1-1-1983

A simulation model of a robotic assembly line.

Chen-Fa Sun

A SIMULATION
MODEL OF A ROBOTIC ASSEMBLY LINE

by

Chen-Fa Sun

A Thesis
Presented to the Graduate Faculty
of Lehigh University
in Candidacy for the Degree of
Master of Science
in
Industrial Engineering

Lehigh University
July, 1983

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment for the Degree of Master of Science.

July 8, 1983
Date

Professor in Charge

Chairman of Department

ACKNOWLEDGEMENTS

I would like to extend my sincere thanks and appreciation to Dr. John W. Adams for his advice, encouragement, and guidance in the role of major advisor; and to Dr. Mikel P. Groover for his support as minor advisor.

In addition, I would like to thank all of the members of the Industrial Engineering Department at Lehigh University for making my graduate studies thoroughly worthwhile and enjoyable.

Table of Contents

ABSTRACT

A Simulation Language for Alternative Modeling (SLAM) computer program was used to help analyze some important factors arising in connection with assembly by robot. These factors were used as parameters in the program and changed individually to obtain different System's performance. Then the relationships between system's performance and those parameters were generated by using statistical methods.

This thesis includes a description of a special assembly system, model building for this system and discussion of the results. For each set of parameters, several executions of program have been made by changing the random number only. The statistical analysis is all based on these data group.

1. INTRODUCTION

In a conventional assembly system, the assembly activities are separated into several steps, each step being the placement of a specific part in the assembly. These steps are assigned to a series of stations which are operated by either persons or special-purpose machines. The work proceeds from station to station and finished assemblies come out of the final station. A manual assembly, typically has low amount of output, low accuracy, poor repeatability and poor resistance to errors and fatique. Although the station's motions can be assigned with more flexibility, this type of assembly line (operated by humans) is difficult to achieve a high product quality, high equipment utilization and high production rate. A special machine, typically a one-of-a-kind device is built to assemble one product or subassembly for its entire productivity life. So the station's motions are simple and are fixed to a pattern. It is therefore difficult to change the machine to accommodate changes in the product. This type of assembly(operated by special machines) has limited the flexibility which can not be changed easily to produce another type of product.

In recent years, industrial robots have found practical and economic application in manufacturing environments performing such tasks as spot welding, palletizing, paint spraying, machine loading and unloading, machine-to-machine transfer and material handling tasks. It can not only be used to do a repetitive operation and because of its programming ability, also be easily switched to do another series of operations by unloading and loading different well prepared programs. By letting these properties to be used in a batch size multi-product assembly line, it is possible that the assembly process can be carried to completion at a single station (which is operated by robot).[7],[8],[11],[12] Moreover, we can provide sufficient stations operating in parallel to attain the desired production rate. If one assumes that a small percentage of any assembly job will require manual intervention, then efficient deployment of lead men at phased parallel stations will allowed the roving men to proceed logically from station to station to lend a hand at critical stages of assembly. This system is less sensitive to production loss due to individual station downtime and has high product quality, high production rate, low in-process inventory and is less disruptive to production schedules.

These thesis will discuss some factors which may affect the performance of an assembly system. A Simulation Language for Alternative Modeling (SLAM) computer program has been used to simulate this assembly system. Several factors such as process time, robot's breakdown rate, the probability of having a jam in assembly and time needed for solving the jam are treated as parameters. From the results of simulation program, we can find out the relationship between the parameters and the system's performance.[2]

2. SYSTEM DEFINITION

The first step in the simulation application consisted of system definition.

2.1 Palletizing line

In the first subsystem, the blank pallet and oriented parts come in to the palletizing station, then the placer picks up the part and puts it on the pallet at the proper location. The pallets are prepared in batches of N, and each pallet contains n different parts. To prepare a batch of N pallets, the N pallets are circulated through the placer system n times. On each pass the placer puts a different part on the pallet, and after a pallet completes its n-th pass all n parts are on the pallet . When the n-th part is placed on the N-th pallet, the entire batch of N pallets is complete and ready for assembly. The circulating conveyor system on which the pallets are traveling must be large enough to contain all N pallets simultaneously. The next batch of blank pallets will come into the palletizing line and repeat all the operations again.

2.2 Assembly line

In the second subsystem, the assembler picks up the parts from the pallets and assembles them on a base plate. However, for certain parts, the assembly operation can not be performed by the assembler. In this case the base plate will be routed to another station for special treatment. This treatment can be performed manualy or by some special purpose machine. Meanwhile, the assembler and the pallet in assembly station must wait for the base plate until it comes back from the other station after completing a specific operations.

After the base plate is returned, the assembler keeps on assembling until another special treatment is needed or to the end of assembly operation. Whenever it reaches the end of assembly operation, The pallet and base plate will be routed out of the assembly station and next pallet will come in (if there is a pallet waiting), or the assembler will be idle.

These two subsystems are connected by a conveyor: from the output of the first subsystem to the input of the second subsystem. After completing assembly from assembly station, the blank pallet will be routed back to palletizing station and the base plate with final product will be routed to another area for unloading and inspection. Then the base plate will be routed back to assembly station again.

When the palletizing and assembly are in progress, there is a probability that a jam will occur. All jams are removed by a human operator.

3. MODEL BUILDING

3.1 Factors affect the system's performance

Among the whole system, the main concern is to find a proper input which will yield an optimal performance. Some factors which will affect these values are listed as follow:

1. pallet's input rate

   An input rate which is too high does not increase the performance of the system but would just build up a long queue which increases cost. An input rate which is lower than needed would cause the line to be idle more frequently and the yield will be low.

2. probability of a jam which is caused by improper orientation of the part or inaccuracy of the robot

   The placement of a part is not necessarily successful, and if not the intervention of a human operator is required. It is assumed that the probability of failure is known for each part, say p_i for the i-th part. Morever, when human intervention is required, there is an additional delay, say d.

3. robot's breakdown rate and repair time

   In this assembly system, only the robots are directly processing the parts. So that the robot's breakdown will greatly influence the output of the system especially when the repair time for breakdown comparing to the process time is significant. In general the repair times is so significant that it is impossible to treat the breakdown as a factor in this system. Therefore, the robot's breakdown is assumed not to occur in the execution of simulation. In the real world, this effect can be estimated for the long run.

4. process time for the individual operations

   The time required for the placement of each part is assumed to be known, say t_i for the i-th part.

5. the speed of the robot

   In some caess, the robot's movement can be speeded up. This will reduce the process time but the probability of a jam increases.

6. time for pallet to feed into the station and its transfer times

   Pallet transfer time and time for pallet to be fed into the station will have a great influence to the system's performance when these times are significant comparing to the process time. If these times do not appear significant, it can be treated as constant or just neglects it(a too small time value used in the simulation will greatly increase the program's execution time). In this thesis, all these times are treated as constant.

7. the effect of the batch size

   A large batch size will build up a longer queue and will need a larger circulating conveyor to contain all N pallets simultaneously. A small batch size will cause changing robot's program and/or gripper more frequently and the change-over time will become significant.

3.2 Performance evaluation

The performance of the system is judged by the following:

1. number of product completed(For the assembly station, pallets completed is the index. For the palletizing station, parts used is the index).

2. utilization of the robot (percentage of the idle time of the robot).

3. maximum queue length

4. how many pallets and base plates are needed to supply the whole system.

5. total time spend in the system by the pallet.

3.3 Model development

In the model developement, all the pallets are treated as entities.[1] Along with them, several attributes are assigned to represent their characteristics. These characteristics include the times that pallet first arrived at both lines, the number of the parts currently on the pallet and the process time needed for the current operation. The process times and the probabilities of having a jam for all the parts are stored in memory arrays. All the pallets queuing on the line are grouped into several files and all the movements of the pallets are treated as activities.

The pallets(entities) arrive at the palletizing line with a predetermined rate. After arriving at the palletizing line, the pallet wait for seizing the resources(placer and part) in a waiting file. When a pallet seizes the placer and part, its attributes are reviewed, then the process time needed and the probability of having a jam and the time needed to solved the jam are determined from the memory arrays. Whenever placing a part on a pallet is completed, the placer is released and the next pallet comes in(if there is one waiting) and seizes the resources again. The original pallet is routed to a checking point(gate) and then will be routed back to waiting file or out of palletizing line according to the values of its attributes(to check how many parts already on the pallet). Before entering the palletizing line, there is another checking point(gate) in which a counter and a setting number(batch size) are used to prevent more than N pallets from coming into the waiting file in the same time.

The pallet which carries the parts enters the assembly line with a predetermined rate. After arriving at the assembly line, the pallet waits for seizing the resources(assembler and base plate) in a waiting file. When a pallet seizes the placer and base plate, its attributes are reviewed, then the process time needed and the probability of having a jam and the time needed to solved the jam are determined from the memory arrays. In the same time, another memory array is also reviewed to determine which steps the special treatments will be needed. Whenever these steps are reached, the base plate will be routed to another station for processing and then be routed back. After assembling a product is completed, the assembler is released and next pallet comes in(if there is one waiting) and seizes the resources again. The original pallet is routed out of the system and will release the base plate after some time period.

The whole system was then programmed in the SLAM format. The number of operations and the process time for individual operation could be assigned to any values to simulate different product which would like to be produced in this system. In the actual execution of the simulation, the number of operations for assembling a product is 20 and the average process time is assigned to 8.5 second. The base plates available at the beginning is assigned to 30. Acctually, after taken some simulation runs, we found 2 base plates are enough for the system if there has no time delay between pallet is routed out and then release the base plate. Approximately 17000 parts were used for each 24-hours simulated period. The time unit was equal to 1 second.

4. STATISTICAL ANALYSIS OF THE RESULTS

Two statistical methods were used to analyse the results of the simulation.

The first method used is regression. This method can help find the relationship that exists between the independent variables and the dependent variable. Two types of model used are listed as follow: [2], [3]

1. nonlinear model with exponential relationship

   $y=ab^x$

2. polynomial regression model

   $y=b_0+b_1x+b_2x^2+\cdots\cdots+b_rx^r$

The second method used is to prove whether the differences existing between two group of results from different set of parameters. The equation is listed as follow: [4]

$$N=\mathrm{Max}\ (n,\ \{(2s^2h^2)/d^{*2}\}^+)$$

where

$s^2=(s^2_1+s^2_2+s^2_3+\cdots+s^2_k)/k$

h: parameter determined by n, p and k

s_k: sample variance of k group

n: number of samples in a group

p: confidence level

d*: preference zone

k: number of groups

5. SIMULATION RESULTS

5.1 Probability of having a jam vs. performance

Whenever the probability of having a jam increases, the utilization of the robots in both line decrease linearly.(see fig. A,B). The output of the palletizing line also decreases linearly,(fig. F) but the output of the assembly line does not change siginificantly. The time spent in system by the pallets is proportional to the square of the probability of having a jam. The maximum queue observed before the work station has quadratic relation with the probability of having a jam(fig. C,E,I,D).

5.2 Time needed for solving the jam vs. performance

When the time needed for solving the jam decreases, the utilization of the robot in the assembly line decreases(fig. p, linear relationship), but the utilization of robot in the palletizing line does not change significantly. The output of the palletizing line increases linearly,(fig. Q) but the output of the assembly line does not change. The time spent in system by the pallets (and maximum queue observed before work station) in both line decrease, and is proportional to the square of the time needed for solving the jam (fig. U,T,S). With only one exception.(fig. R, a linear relationship, the pallet's in system time when in palletizing line)

5.3 Processing time vs. performance

When the process time of the operations decreases(from 100% improves to 70%), the utilization of the robots in both line decreases linearly.(fig. W,V) The output of the palletizing line increases linearly (fig. X), but the output of the assembly line does not have a significant change. The time spent in system by the pallets and maximum queue observed before the work station in both lines decreases and is proportional to the square of the processing time(fig. Y, Z,YY,ZZ).

5.4 Time between successive pallet's arrival vs. performance

Whenever the time between successive pallet's arrival decreases, the utilizations of the robots in both line increase linearly until the 100% utilization rate reached.(fig. K,H) The outputs of these two lines increase and have exponential relationships(fig. J,G). The time spent in system by the pallets and the maximum queue observed in both lines decrease with respect to the change of processing time(cubic relationships).

6. DISCUSSION

6.1 Reliability of the results

All the results obtained from the simulation were used to generate several emprical equations by means of regression. Accompanied with the equations generated, a correlation coefficient or a standard deviation has been caculated to make sure the equation is a good fit. All the equations have significantly high correlation coefficients.

6.2 The time spent in system by the pallets and maximum queue observed

From the results listed before, whenever the factors changed, the time spent in system by the pallets always has a similar variation with the maximum queue observed and all have square or cubic relationships. This means that these two types of performance change more quickly than those of factors.

Both lines have a lower bound of the maximum queue observed. In the assembly line the value is 2. In the palletizing line the value is 112 which is a little higher than the batch size(100) and 2 more higher than the initial value(110 Was assumed in the simulation).

6.3 Robot's utilization

From the results listed before, The robot's utilization always changed linearly when factors changed except Vs. the time needed for solving the jam changed in the palletizing line. In this exceptional case, the robot's utilization stayed around 100% which means that in this palletizing line, the robot is always too busy and the effect of the time needed for solving the jam is not so significant to affect it.

6.4 Output of the system

From the results listed before, except under the effectiveness of changing the time between successive pallet's arrival(exponential relationship vs. output and has an upper bound), the output of the palletizing line has a linear relationship with respect to all the factors. The output of the assembly line does not have a significant change for all of these cases, and the factors do not change the production rate of the assembly line. The reason is that the pallet's input rate is too low to restrict the effectiveness of the other factors.

7. CONCLUSIONS

From the results and disussion listed before, we can conclude the following:

1. Maximum queue observed and the time spent in the system by the pallet have simillar variation when the factors(pallet's input rate, probability of having a jam, time needed to resolve a jam and processing time) changed. So, these two types of performance of the system can be seen as the same index of the performance.

2. The output of these two lines(palletizing line and assembly line) has an upper bound and this upper bound is greatly influenced by the pallet's input rate(or time between successive pallet's arrival). A too low input rate will reduce the value of this upper bound(certainly can not yield a high output) and a too high input rate does not increase the output of the system(because there is an upper bound). So, an optimal range of the pallet's input rate which can yield the best performance exists and can be found(obtain the highest output with the lowest maximun queue observed).

3. Reducing the batch size in the palletizing line will reduce the length of the circulating conveyor and the in-

process inventory(the pallets needed are less too). But a too small batch size will result in excessive change-over time of the work station and the pallet's circulating time delay. So, theoretically, there is an optimal range of the batch size , and this range can not be found prior some cost informations(cost for pallet, cost for conveyor, etc.)are obatained.

4. The system's output is linearly related to the probability of having a jam, and the time needed to resolve a jam. Whether or not it is economical to increase output by reducing the probability of having a jam is an economic question. That is due the economic gain from increased output exceed the cost of reducing the probability of having a jam.

REFERENCES

1. Pritsker, A. A. Introduction to Simulation and SLAM. New York: Halsted Press, 1979.

2. Walpole, R. E. Probability and Statistics for engineers and scientists. 2nd ed. New York: Macmillan, 1978.

3. Simmons, Donald M. Nonlinear Programming for Operations Research. N.J.: Prentice-Hall, 1975.

4. Gibbons, Jean D. Selecting and Ordering Populations. New York: Wiley, 1977.

5. Van cleave, David A. One Big Step For "Assembly In The Sky." Nov. 1977 Iron Age.

6. Abraham, R. G. State-Of-The-Art In Adaptable-Programmable Assembly Systems. S.M.E. Dearborn, MI. 1977 (technical Paper MS77-757)

7. Dunne, Macurice J. An Advanced Assembly Robot. 1976, Volume II, Industrial Robots.

8. Nevins, James L. and Whitney, D. E. Computer-Controled Assembly. Scientific American. Feb. 1978.

9. Whitney, Daniel E. and Nevins, J. L. Applying Robots in Industrial Assembly.
Robotics Research and Advanced Applications, ASME, 1982.

10. Warnecke, H. J., Schweizer, M. and Fraunhofer, H. An Adaptable Programmable Assembly System Using Compliance and Visual Feedback. 10th International Symposium on Industrial Robots Italy, 1980.

11. Martensson, N. and Johansson, C. Subassembly of A Gearshaft by Industrial Robot. 10 th International Symposium on Industrial Robots Italy, 1980.

12. Badger, M. A. The Use of The DEA PRAGMA A3000 Robot in The Assembly of Automative Components.
10th International Symposium on Industrial Robots Italy, 1980.

13. Kohno, M., Sugimoto, K., Matsumoto, Y. and Suzuki, T. A Robot For Assembling Variety of Mechanical Parts. 10th International Symposium on Industrial Robots Italy, 1980.

14. Miller, Richard K. Robots in Industry, Applications For Assembly. SEAI Institute, Madison, GA.

15. Nevins, J. L. and Whitney, D.E. Research on Advancrd

Assenmbly Automation. Computer, December, 1977.

16. K.Feldmann and G.Schillack A Flexible Assembly System Using Industrial Robots. 8th International Symposium On Industrial Robots.

I. THE APPENDIX

I.1 TABLE

****Palletizing Line****

Table A

(probability of having a jam)

.01	.008	.006	.004	.002	
1.0	1.0	.9917	.9345	.9105	
1.0	1.0	.9630	.9294	.9092	
1.0	1.0	.9697	.9316	.9072	
1.0	.9943	.9697	.9384	.9137	
1.0	1.0	.9697	.9428	.9137	
1.0	1.0	.9898	.9338	.9070	
1.0	1.0	.9742	.9451	.9114	
1.0	.9985	.9809	.9339	.9182	
1.0	1.0	.9897	.9697	.9249	
1.0	1.0	.9674	.9339	.9070	
1.0	.99928	.97658	.9394	.91228	: mean

* The entry in the table is the utilization of the robot.

Table B

(probability of having a jam)

.01	.008	.006	.004	.002	
8079	8519	8942	9025	9049	
8607	8491	8946	9025	9025	
8476	8633	8862	8890	9025	
8497	8834	9000	9000	9049	
8476	8683	8834	8946	8973	
8456	8792	8918	9000	9025	
8668	8770	8890	8890	9000	
8254	8828	8917	8946	9000	
8159	8778	8831	8890	9025	
8437	8820	8890	8918	9025	
8410.9	8714.8	8903	8953	9019.6	: mean

* The entry in the table is the the number of parts used in the palletizing line.

****Palletizing Line****

Table C

(probability of having a jam)

.01	.008	.006	.004	.002	
28200	25990	25540	23940	23310	
26840	26280	24500	23720	23630	
27410	26200	24980	23910	23430	
27480	26380	24800	24160	23420	
27170	26000	24630	24170	23370	
27060	26590	25630	23900	23440	
26820	25480	24940	24040	23440	
28060	27000	25580	24080	23320	
28470	27440	26360	25200	23340	
27930	26750	24820	23960	23470	
27544	26411	25178	24108	23417	: mean

* The entry in the table is the time spend in the system by the pallet.

Table D

(probability of having a jam)

.01	.008	.006	.004	.002
140	121	114	112	112

* The entry in the table is the maximum queue observed.

****Assembly Line****

Table E

(probability of having a jam)

.01	.008	.006	.004	.002	
.9422	.9418	.9157	.9087	.8929	
.9365	.9416	.9097	.9187	.8967	
.9494	.9143	.9201	.9065	.9006	
.9552	.9412	.9182	.9009	.8948	
.9545	.9260	.9331	.9104	.8987	
.9513	.9279	.9279	.9065	.8909	
.9338	.9401	.9139	.9123	.8987	
.9410	.9181	.9221	.9123	.8928	
.9572	.9357	.9103	.9026	.8909	
.9260	.9107	.9104	.9045	.8948	
.94471	.92974	.91814	.90831	.89518	: mean

* The entry in the table is the utilization of the robot.

Table F

(probability of having a jam)

.01	.008	.006	.004	.002	
432	436	431	432	432	
435	437	436	436	437	
437	437	437	437	437	
437	435	437	436	437	
436	437	436	437	437	
437	437	437	437	437	
437	436	435	437	437	
436	436	437	437	437	
437	437	436	437	437	
437	432	437	437	437	
436.1	436	435.9	436.3	436.5	: mean

* The entry in the table is the products completed

****Assembly Line****

Table G

(probability of having a jam)

.01	.008	.006	.004	.002	
254.1	201.3	206.2	200.6	185.2	
242	230.3	201.1	222.2	184	
313.4	216.5	217.3	198.2	183.6	
283.4	251.7	228.1	192.9	188.5	
297.2	236.2	226.9	202.9	181.9	
266.7	222.3	223.9	201.5	189.9	
237.5	260.6	208.4	201	185.9	
245.4	216.5	214.5	208.7	193.6	
297.2	275.9	198.5	193.5	186.9	
236.8	253.3	205.7	193.5	185.8	
267.37	236.46	213.1	200.75	186.53	: mean

* The entry in the table is the time spend in the system by the pallet.

Table H

(probability of having a jam)

.01	.008	.006	.004	.002
5	4	3	2	2

* The entry in the table is the maximum queue observed.

****Palletizing Line****

Table I
(time needed for solving the jam)

200	180	160	140
1.0	1.0	1.0	1.0
1.0	1.0	1.0	.9897
1.0	1.0	1.0	1.0
1.0	1.0	1.0	.9772
1.0	1.0	1.0	.9865
1.0	1.0	1.0	.9944
1.0	.9983	1.0	.9803
1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0
1.0	.99983	1.0	.99272 : mean

* The entry in the table is the utilization of the robot.

Table J
(time needed for solving the jam)

200	180	160	140
8079	8324	8550	8844
8607	8614	8853	8950
8476	8594	8751	8773
8497	8701	8768	8911
8476	8595	8768	8833
8456	8594	8768	8930
8668	8763	8863	8891
8254	8406	8550	8772
8158	8388	8662	8769
8437	8424	8568	8891
8410.8	8540.4	8710.1	8856.4 : mean

* The entry in the table is the the number of parts used in the palletizing line.

****Palletizing Line****

Table K
(time needed for solving the jam)

200	180	160	140	
28200	27670	26660	25890	
26840	26810	26150	25600	
27410	26980	26710	26170	
27480	26530	26450	25200	
27170	26850	26380	25570	
27060	26710	26360	25770	
26820	26180	25470	25130	
28060	27530	27390	26400	
28470	27410	27140	26360	
27930	27320	26710	26160	
27544	26999	26542	25825	: mean

* The entry in the table is the time spend in the system by the pallet.

Table L
(time needed for solving the jam)

200	180	160	140
132	125	121	118

* The entry in the table is the maximum queue observed.

****Assembly Line****

Table M
(time needed for solving the jam)

200	180	160	140	
.9422	.9304	.9203	.9221	
.9365	.9340	.9193	.9305	
.9494	.9246	.9405	.9278	
.9552	.9332	.9298	.9242	
.9545	.9280	.9358	.9116	
.9513	.9194	.9149	.9101	
.9338	.9463	.9313	.9191	
.9410	.9345	.9223	.9116	
.9572	.9325	.9273	.9267	
.9260	.9332	.9294	.9217	
.94471	.93161	.92809	.92054	: mean

* The entry in the table is the utilization of the robot.

Table N
(time needed for solving the jam)

200	180	160	140	
432	431	431	432	
435	436	437	437	
437	437	436	436	
437	437	437	437	
436	437	437	437	
437	437	437	436	
437	435	437	437	
436	435	437	437	
437	436	437	437	
437	437	436	437	
436.1	435.5	436.2	436.3	: mean

* The entry in the table is the products completed

****Assembly Line****

Table O

(time needed for solving the jam)

200	180	160	140
254.1	229.5	209.9	206.7
242	229.6	205.2	217.5
313.4	218.8	237.1	208.2
283.4	235.5	218.8	205.9
297.2	230.1	230.3	198.0
266.7	205.4	199.8	193.5
237.5	238.3	212.8	200.7
245.4	233	208.8	193.2
297.2	229.7	221.9	209.7
236.8	240.9	213.7	204
267.37	229.08	215.83	203.74

* The entry in the table is the time spend in the system by the pallet.

Table P

(time needed for solving the jam)

200	180	160	140
5	3	2	2

* The entry in the table is the maximum queue observed.

Table Q

****Palletizing Line**** ****Assembly Line****

(ratio of process time)

.9	.8	.7		.9	.8	.7
1.0	.9294	.8833		.8985	.7886	.7252
.9791	.9189	.8775		.8877	.7965	.7008
1.0	.9281	.8739		.8712	.8058	.7437
.9621	.8950	.8757		.8992	.8265	.7281
.9335	.9285	.9027		.8658	.7948	.7295
.9836	.9022	.8776		.8878	.7988	.7276
1.	.9300	.8805		.8765	.8224	.7333
1.	.9385	.9013		.8974	.7992	.7113
.9386	.9469	.8813		.9017	.8087	.7467
1.0	.9253	.8968		.8832	.8004	.7275
.98969	.92428	.88524	-mean-	.8869	.80417	.72737

* The entry in the table is the utilization of the robot.

Table R

(ratio of process time)

.9	.8	.7		.9	.8	.7
8970	9177	9366		443	443	442
9146	9270	9396		448	448	448
9118	9296	9511		448	448	448
9162	9324	9525		448	448	448
9084	9199	9497		448	448	448
9251	9381	9428		448	448	448
9176	9307	9304		448	448	448
8975	9312	9160		448	448	448
8939	9237	9367		448	448	448
9105	9187	9509		447	448	447
9092.6	9269	9406.3	-mean-	447.4	447.6	447.3

* The entry in the left table is the number of parts used in the palletizing line. The entry in the right table is the products completed in the assembly line.

Table S

****Palletizing Line****				****Assembly Line****		
		(ratio of process time)				
.9	.8	.7		.9	.8	.7
25730	23310	22230		219.1	170.9	155.7
24490	23120	22050		206.2	170.5	144.3
25500	23070	22180		192.2	177.1	166.7
24240	22610	22190		224.2	194.0	158.1
24640	23310	22410		187.6	170.1	155.6
24750	22530	22090		202.2	173.3	156.6
25190	23320	22340		196.9	189.8	159.8
26000	23610	22760		216.9	171.8	148.0
25980	23720	22290		235.1	180.7	162.8
256.3	23060	22340		206	175.5	155.1
25215	23166	22288	-mean-	208.63	177.37	156.27

* The entry in the table is the time spend in the system by the pallet.

Table T

		(ratio of process time)			
.9	.8	.7	.9	.8	.7
121	112	112	3	3	2

* The entry in the table is the maximum queue observed.

****Palletizing Line****

Table U

(time between successive pallet's arrivals)

250	230	215	200	197	194	190	180	170
.8823	.9458	.9904	1.0	1.0	1.0	1.0	1.0	1.0
.8925	.9284	.9591	1.0	1.0	1.0	1.0	1.0	1.0
.8791	.9352	.9860	1.0	1.0	1.0	1.0	1.0	1.0
.8768	.9150	.9614	1.0	1.0	1.0	1.0	1.0	1.0
.8679	.9061	.9614	1.0	1.0	1.0	1.0	1.0	1.0
.8746	.9240	.9725	1.0	1.0	1.0	1.0	1.0	1.0
.8836	.9262	.9546	1.0	1.0	1.0	1.0	1.0	1.0
.8656	.9329	1.0	1.0	1.0	1.0	1.0	1.0	1.0
.9059	.9486	1.0	1.0	1.0	1.0	1.0	1.0	1.0
.9060	.9597	1.0	1.0	1.0	1.0	1.0	1.0	1.0
.88343	.93019	.97854	1.0	1.0	1.0	1.0	1.0	1.0

-mean-

* The entry in the table is the utilization of the robot.

Table V

(time between successive pallet's arrivals)

250	230	215	200	197	194	190	180	170
7450	7866	8224	8079	8353	8125	8101	8280	8304
7518	7866	8273	8607	8634	8583	8583	8634	8542
7428	7866	8282	8476	8477	8417	8398	8457	8498
7497	7866	8273	8497	8641	8584	8540	8542	8563
7540	7866	8224	8476	8584	8584	8540	8541	8438
7401	7866	8231	8456	8418	8456	8540	8477	8457
7450	7866	8347	8668	8748	8632	8703	8657	8715
7475	7866	8156	8254	8161	8231	8159	8138	8329
7355	7866	8182	8159	8116	8254	8159	8116	8231
7454	7866	8207	8437	8232	8417	8352	8399	8438
7456.8	7866	8239.9	8410.9	8436.4	8428.3	8407.5	8424.1	8451.5

-mean-

* The entry in the table is the the number of parts used in the palletizing line.

****Palletizing Line****

Table W

(time between successive pallet's arrivals)

250	230	215	200	197	194	190	180	170
26820	27330	28200	28200	27600	28070	28400	28330	28580
26860	26960	27380	26840	27060	27510	27560	27960	28170
26000	26980	28070	27410	27670	27840	28170	28190	28450
25940	26590	26220	27480	26820	27300	27600	27800	28020
25930	26440	26630	27170	27480	26820	27040	27860	28510
26080	26720	26150	27060	27450	27160	27060	27970	28460
26300	26910	26350	26820	26730	27380	27420	27700	27960
25790	26840	26920	28060	28480	27850	28770	29280	29160
27120	27240	26240	28470	28520	28190	28500	26250	29080
27210	26900	27320	27930	27640	27850	27970	28330	29050
26405	26890	26948	27544	27545	27597	27849	27967	28544

-mean-

* The entry in the table is the time spend in the system by the pallet.

Table X

(time between successive pallet's arrivals)

250	230	215	200	197	194	190	180	170
112	113	118	132	138	139	149	175	190

* The entry in the table is the maximum queue observed.

****Assembly Line****

Table Y

(time between successive pallet's arrivals)

250	230	215	200	197	194	1.90	1.80	170
.7657	.8068	.8804	.9422	.9625	.9637	.9914	.9999	1.0
.7573	.8144	.8779	.9365	.9620	.9651	.9809	.9999	1.0
.7436	.8105	.8742	.9494	.9630	.9589	.9937	1.0	1.0
.7846	.8215	.8755	.9552	.9663	.9718	.9914	.9983	1.0
.7553	.8203	.8649	.9545	.9435	.9573	.9942	.9999	1.0
.7528	.8125	.8801	.9513	.9454	.9593	.9943	.9999	1.0
.7534	.8027	.8566	.9338	.9538	.9739	.9945	.9994	1.0
.7280	.8398	.8677	.9410	.9744	.9719	.9941	1.0	1.0
.7601	.8300	.8742	.9572	.9474	.9833	.9959	.9990	1.0
.7556	.8398	.8644	.9260	.9474	.9712	.9839	.9989	1.0
.75564	.81983	.87159	.94471	.95657	.96764	.99143	.99962	1.0

-mean-

* The entry in the table is the utilization of the robot.

Table Z

(time between successive pallet's arrivals)

250	230	21.5	200	1.97	1.94	190	1.80	1.70
345	376	402	432	438	445	451	457	458
349	380	406	435	443	450	455	460	458
349	380	406	437	443	450	453	467	468
349	379	406	437	442	449	458	463	460
349	380	405	436	443	448	459	464	471
349	380	406	437	443	450	459	457	469
349	380	406	437	441	448	454	469	461
349	380	406	436	443	450	456	463	459
349	380	406	437	443	449	457	461	458
349	380	406	437	443	447	458	469	461
348.6	379.5	405.6	436.1	442.2	448.6	456	463	462.3

-mean-

* The entry in the table is the products completed

****Assembly Line****

Table XX

(time between successive pallet's arrivals)

250	230	215	200	197	194	190	180	170
206.5	198.2	223.2	254.1	304.8	306.8	549.2	2293	4439
198.9	199.2	220	242	306.3	331.6	359.7	2678	4553
192.2	198.7	215.3	313.4	337.2	246.2	633.2	1821	3896
214.2	206.2	220.9	283.4	356.9	317.1	463.2	2309	5369
197.9	203.2	206.8	297.2	235	264.3	447.5	2264	3785
198.2	199.2	218.1	266.7	237.7	317	443.1	3352	3950
197.7	193.3	199.2	245.4	309.3	316.7	413.9	2625	4112
186	216.3	209.1	237.5	281.1	311.3	844.8	1479	4713
201.6	209	217.2	297.2	309.3	576.2	777.3	2718	4647
192	205.1	203.7	236.8	255.9	332.3	404.6	1362	4112
198.52	182.35	213.35	267.37	288.22	332	533.65	2290	4396

-mean-

* The entry in the table is the time spend in the system by the pallet.

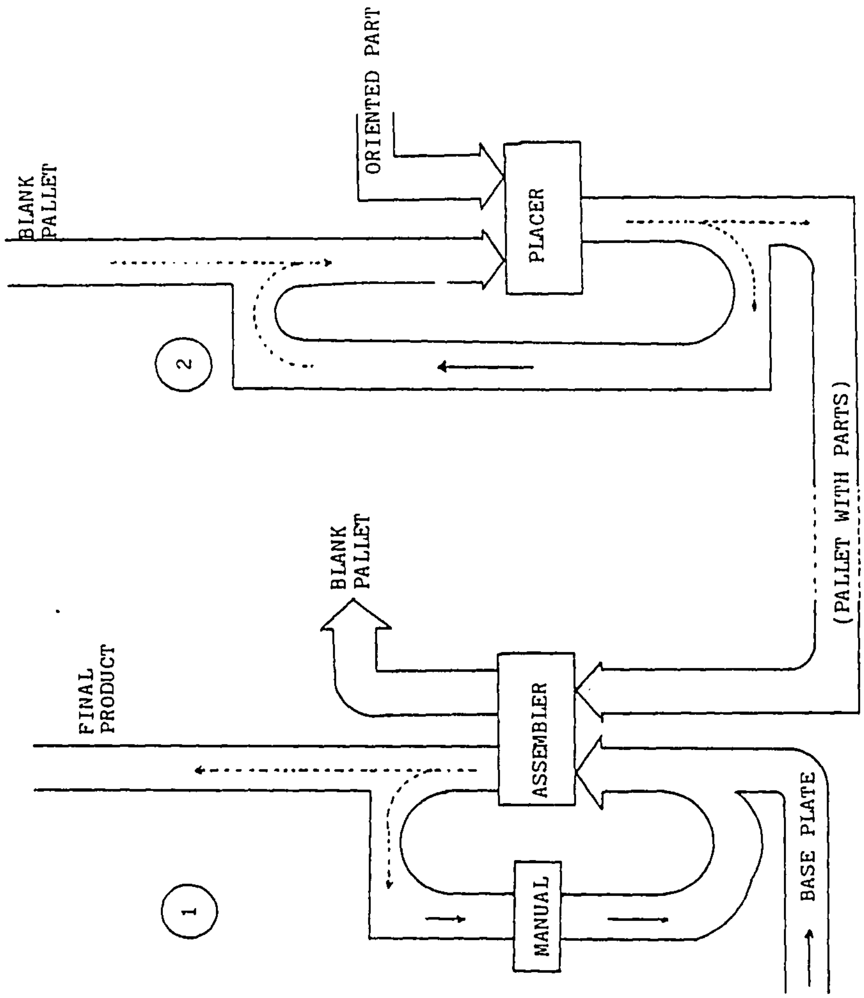
Table YY

(time between successive pallet's arrivals)

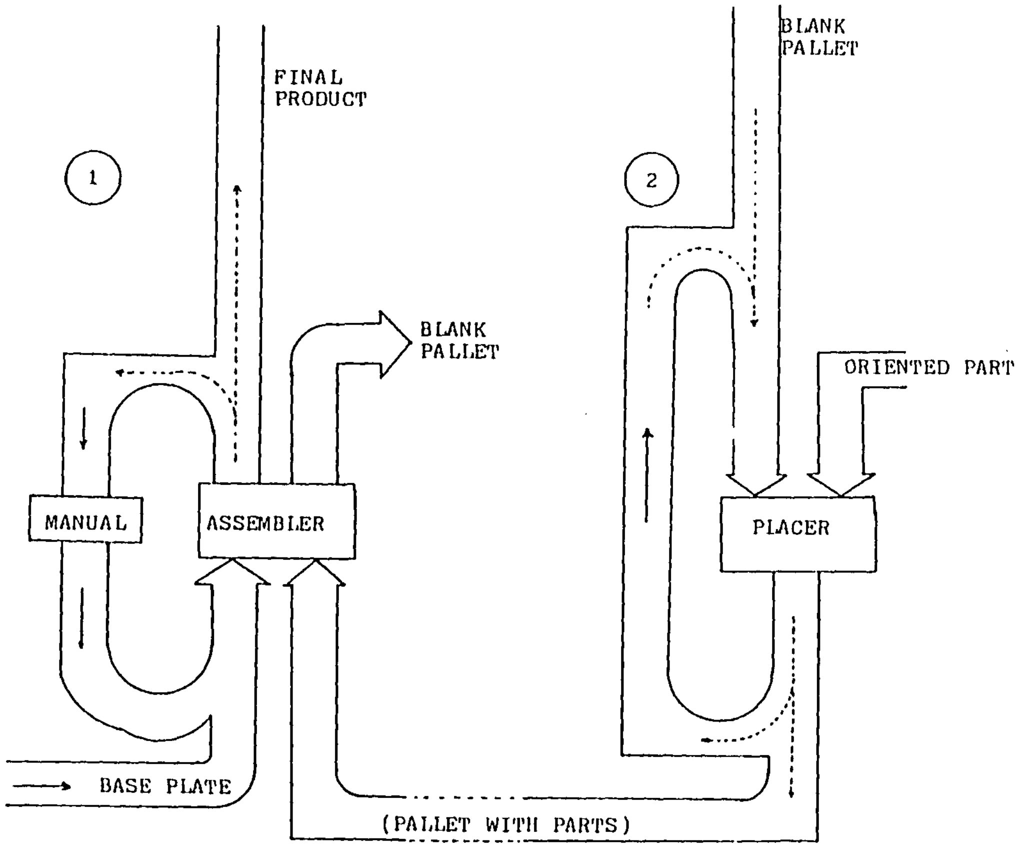
250	230	215	200	197	194	190	180	170
2	2	3	5	4	6	9	29	56

* The entry in the table is the maximum queue observed.

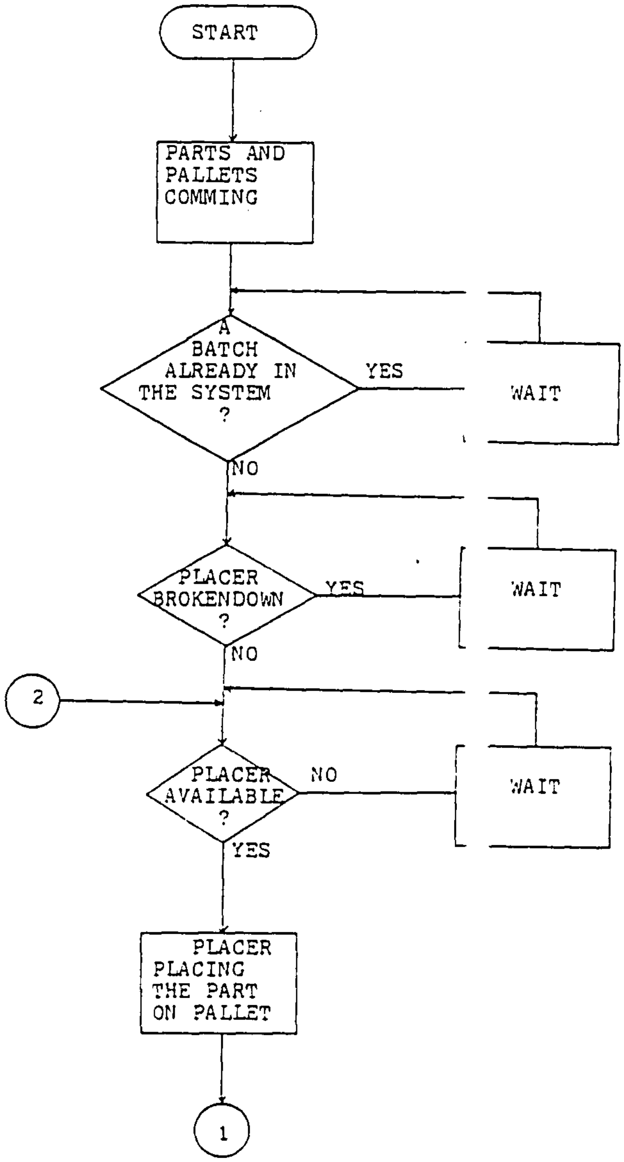
1-2 Figures

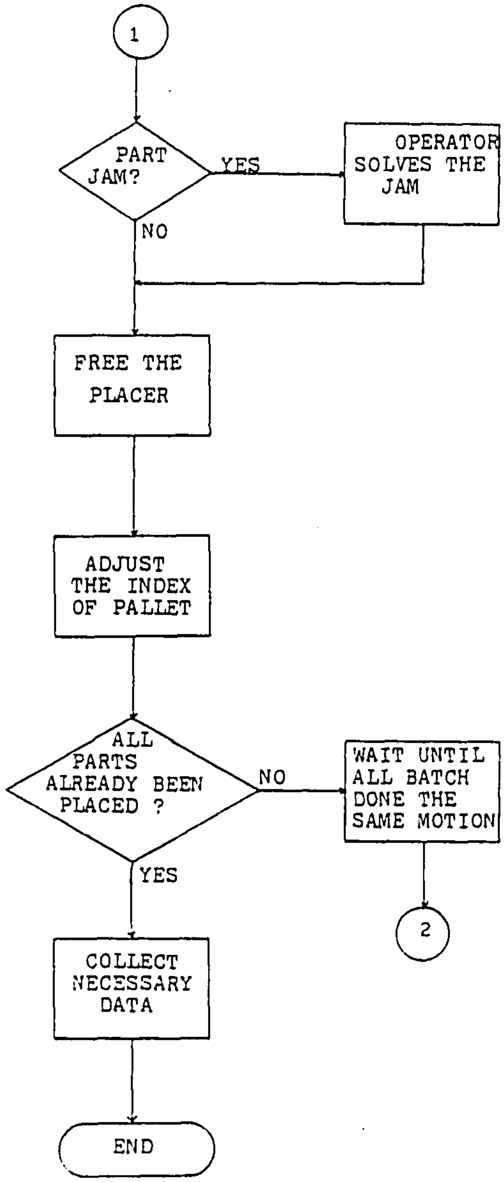


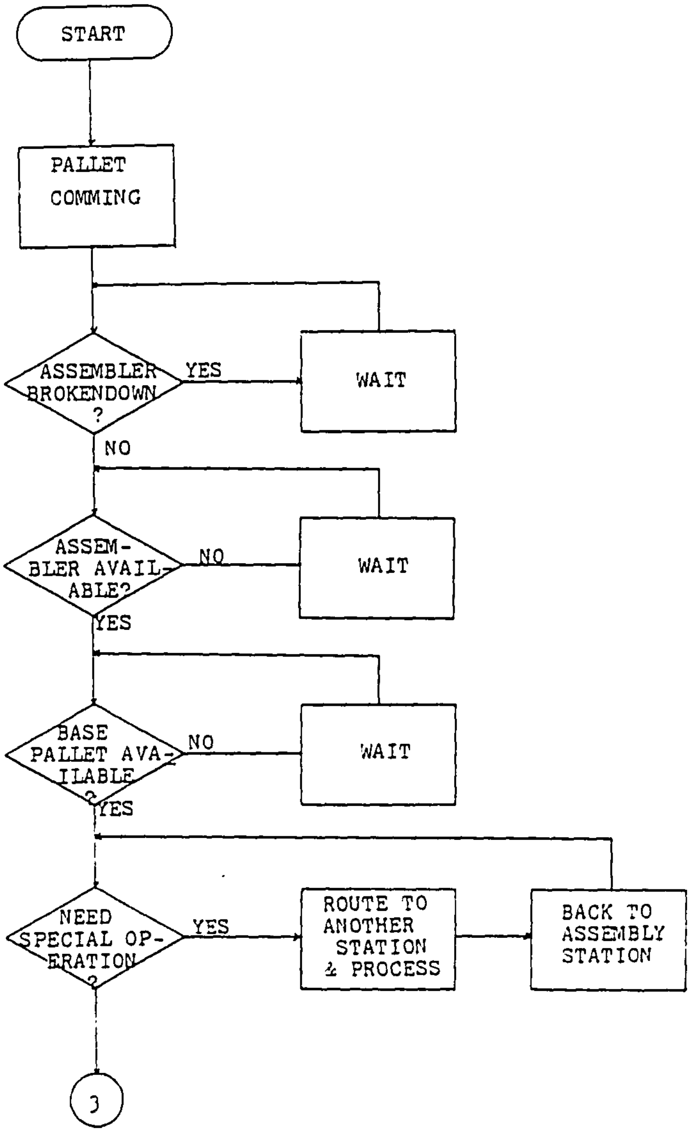
ORIENTED PART
BLANK PALLET
PLACER
2
(PALLET WITH PARTS)
BLANK PALLET
FINAL PRODUCT
ASSEMBLER
BASE PLATE
1
MANUAL

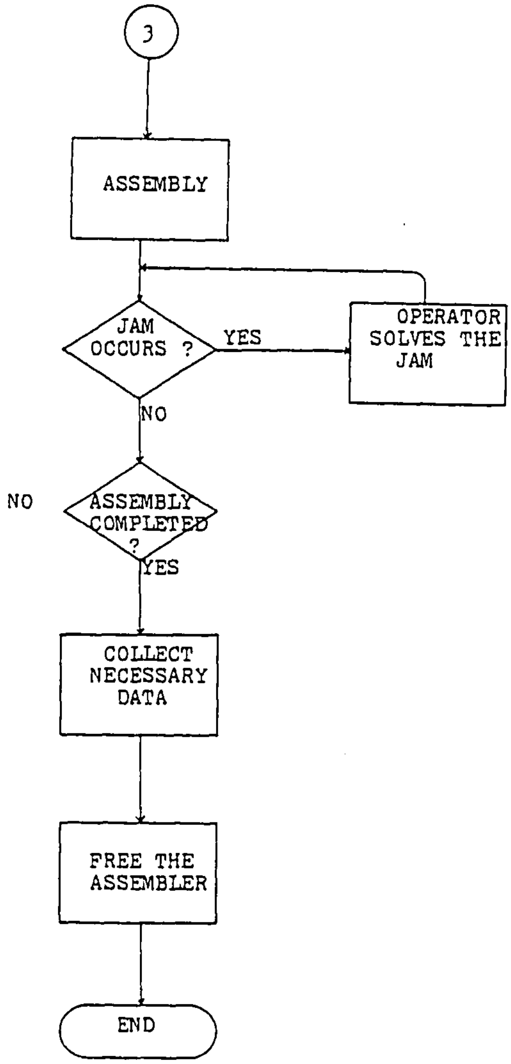

FINAL PRODUCT
1
BLANK PALLET
MANUAL
ASSEMBLER
BASE PLATE
2
BLANK PALLET
ORIENTED PART
PLACER
(PALLET WITH PARTS)

Flowchart:

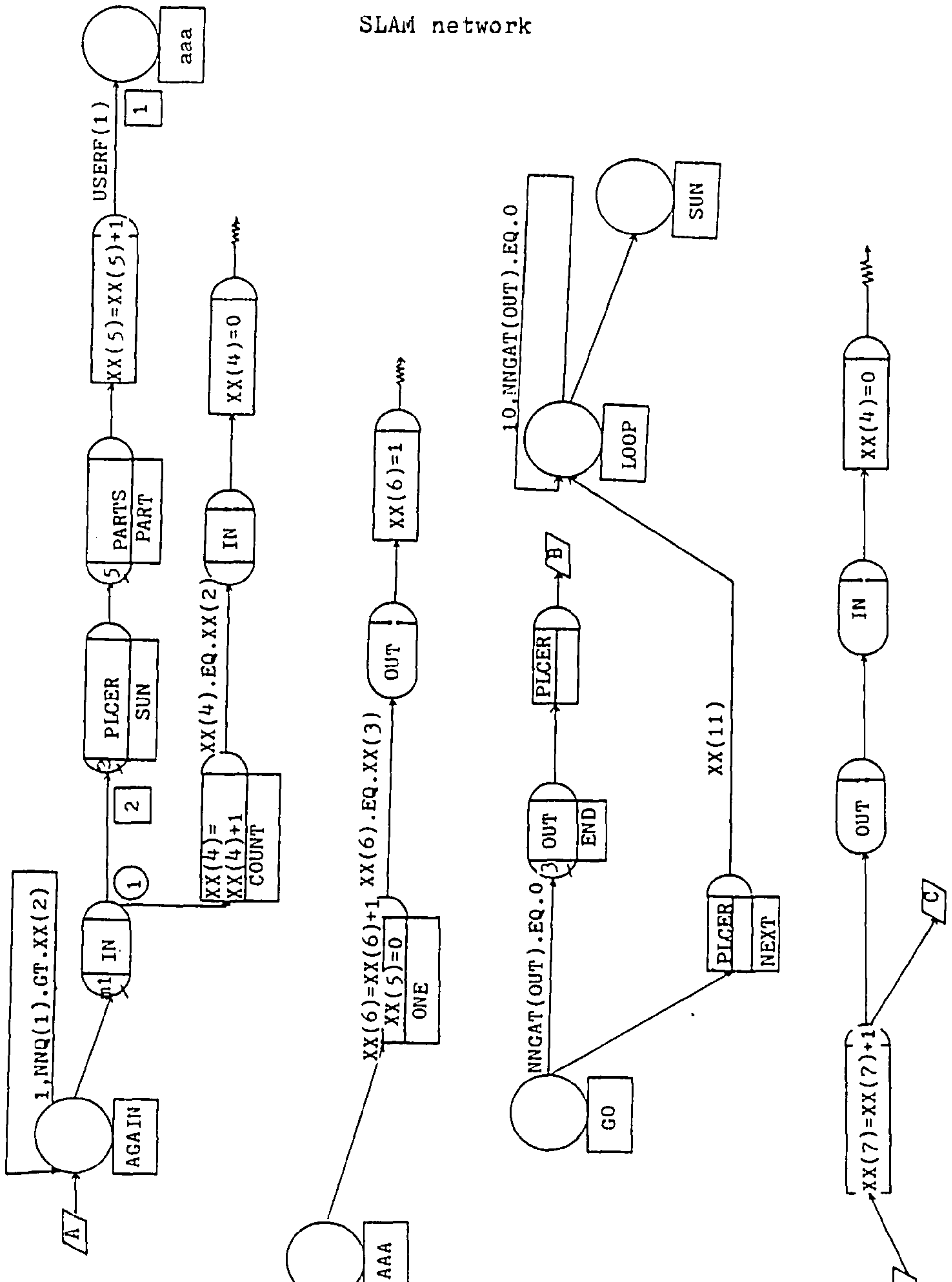

START
PARTS AND PALLETS COMMING
A BATCH ALREADY IN THE SYSTEM ?
YES
WAIT
NO
PLACER BROKENDOWN ?
YES
WAIT
NO
2
PLACER AVAILABLE ?
NO
WAIT
YES
PLACER PLACING THE PART ON PALLET
1

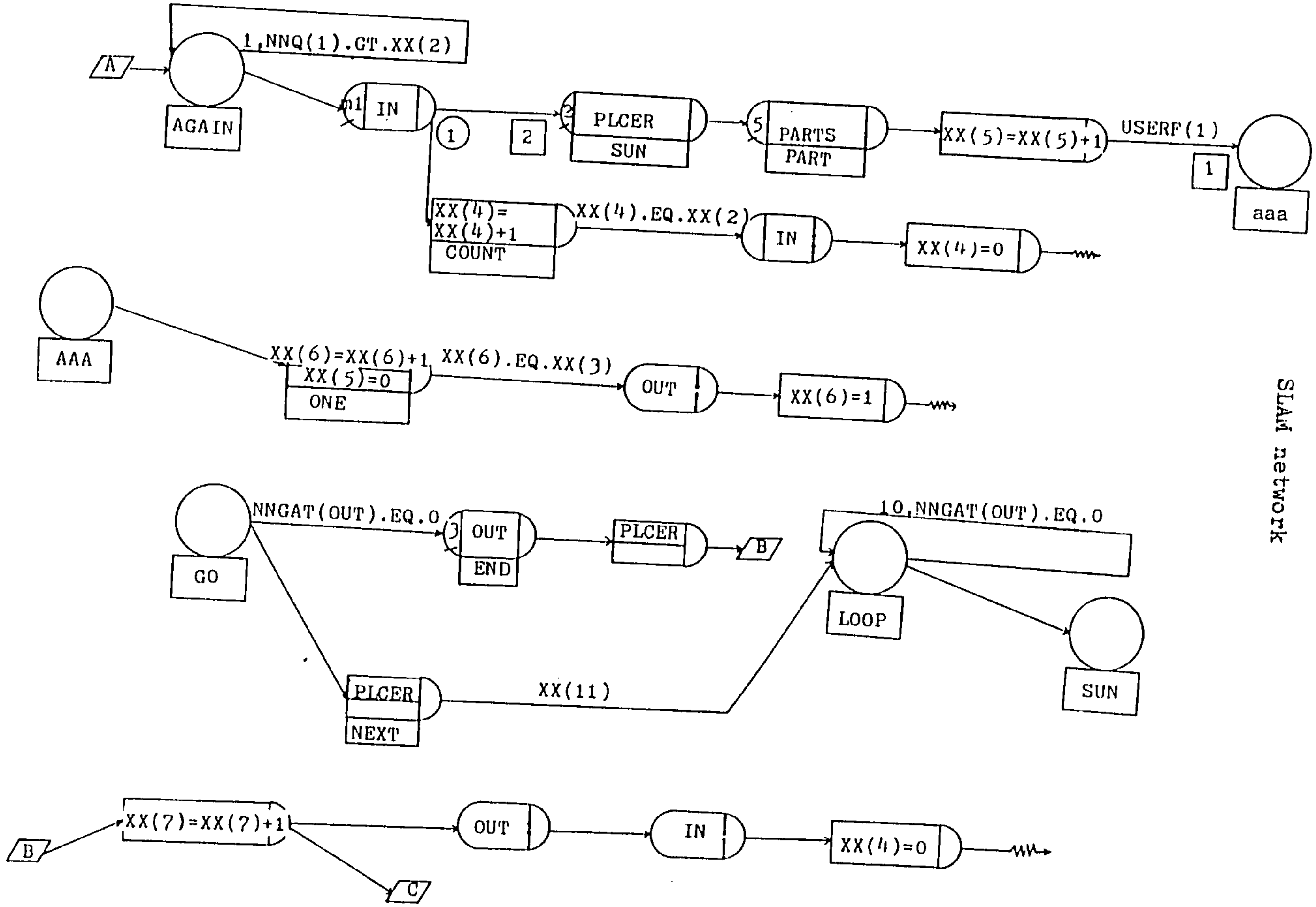

1
PART JAM?
YES
OPERATOR SOLVES THE JAM
NO
FREE THE PLACER
ADJUST THE INDEX OF PALLET
ALL PARTS ALREADY BEEN PLACED ?
NO
WAIT UNTIL ALL BATCH DONE THE SAME MOTION
2
YES
COLLECT NECESSARY DATA
END


START
PALLET COMMING
ASSEMBLER BROKENDOWN ?
YES
WAIT
NO
ASSEM- BLER AVAIL- ABLE?
NO
WAIT
YES
BASE PALLET AVA- ILABLE ?
NO
WAIT
YES
NEED SPECIAL OP- ERATION ?
YES
ROUTE TO ANOTHER STATION & PROCESS
BACK TO ASSEMBLY STATION
3

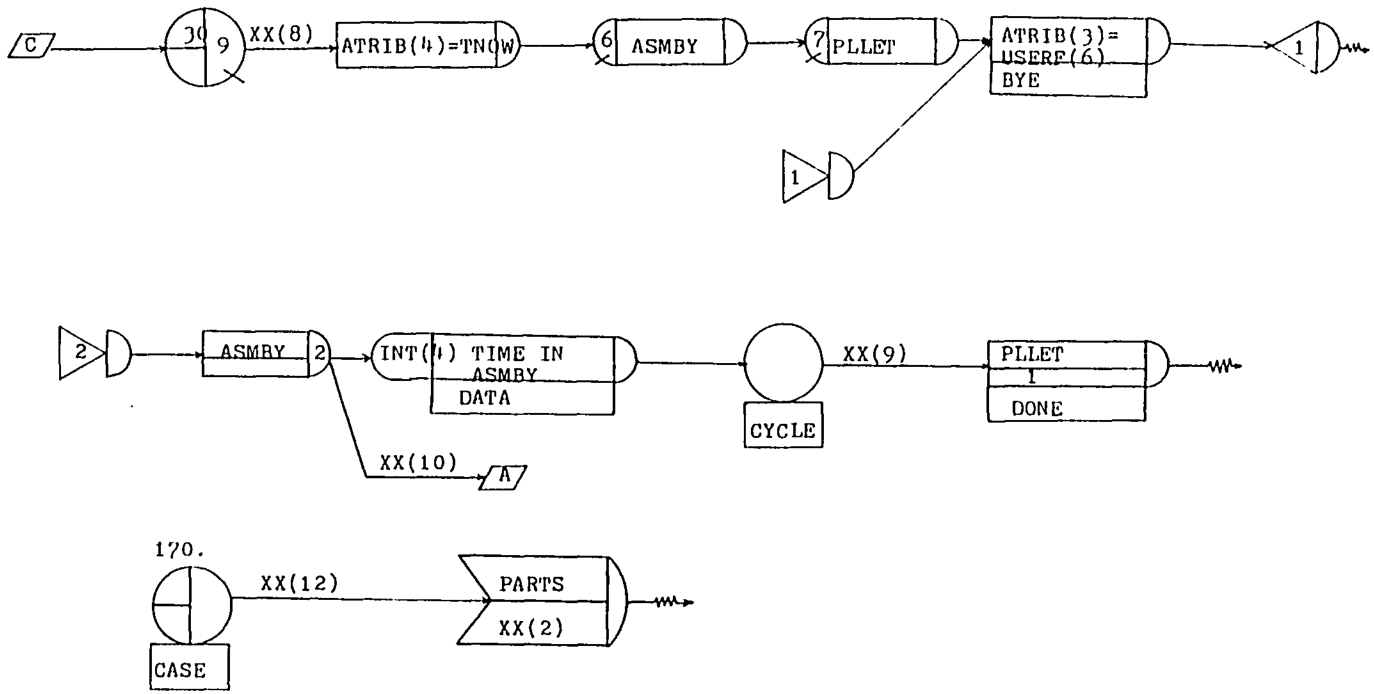

3
ASSEMBLY
JAM OCCURS ?
YES
OPERATOR SOLVES THE JAM
NO
NO
ASSEMBLY COMPLETED ?
YES
COLLECT NECESSARY DATA
FREE THE ASSEMBLER
END

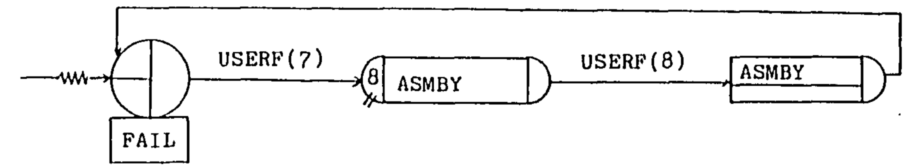
SLAM network

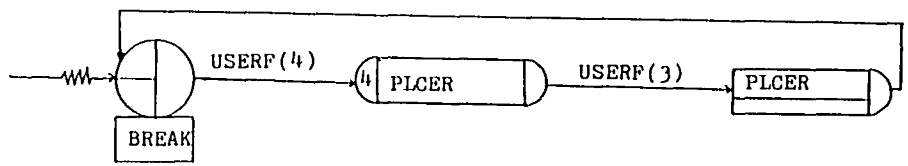




SLAM network


C
30
9
XX(8)
ATRIB(4)=TNOW
6
ASMBY
7
PLLET
ATRIB(3)=
USERF(6)
BYE
1
1
2
ASMBY
2
INT(4) TIME IN
ASMBY
DATA
CYCLE
XX(9)
PLLET
I
DONE
XX(10)
A
170.
XX(12)
PARTS
XX(2)
CASE





RESOURCE

PLCER(1)	4	2	
ASMBY(1)	8	6	
PLLET(30)	7		
PARTS(0)	5		

GATE

IN	OPEN	1
OUT	CLOSE	3

Fig. A

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

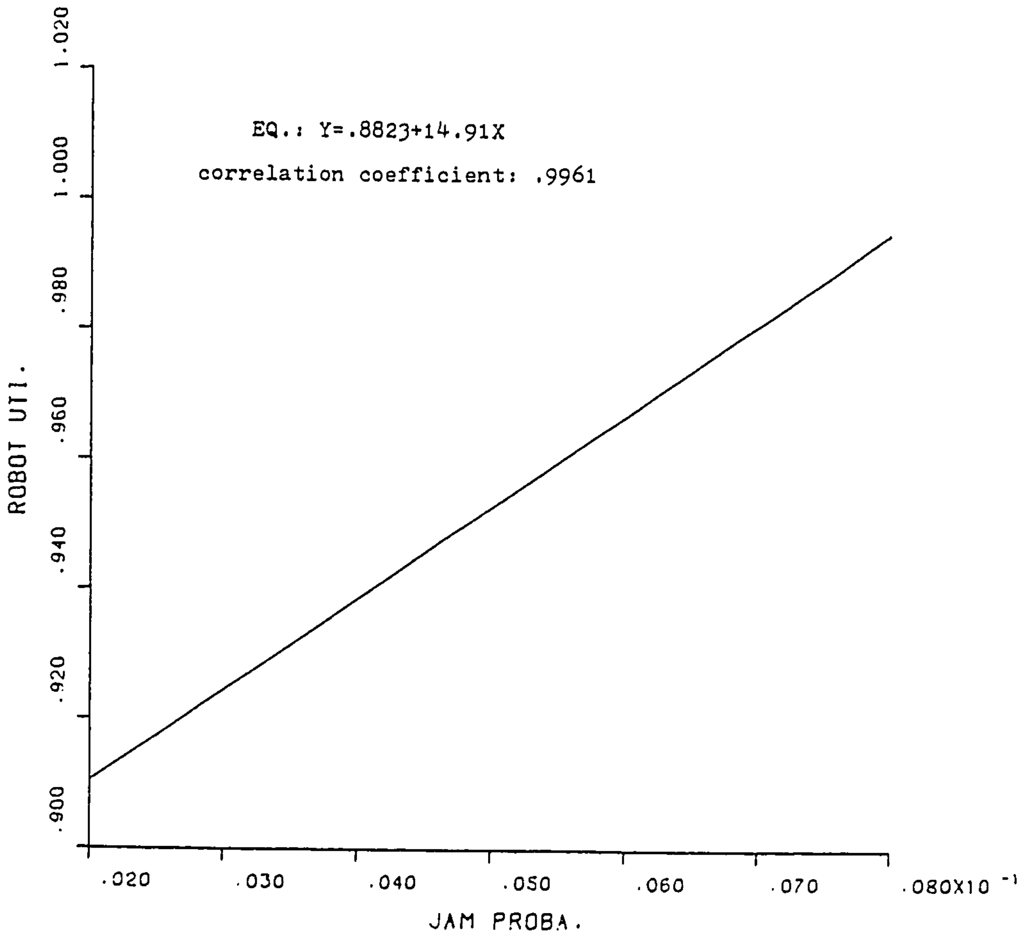


Fig. B

Assembly Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

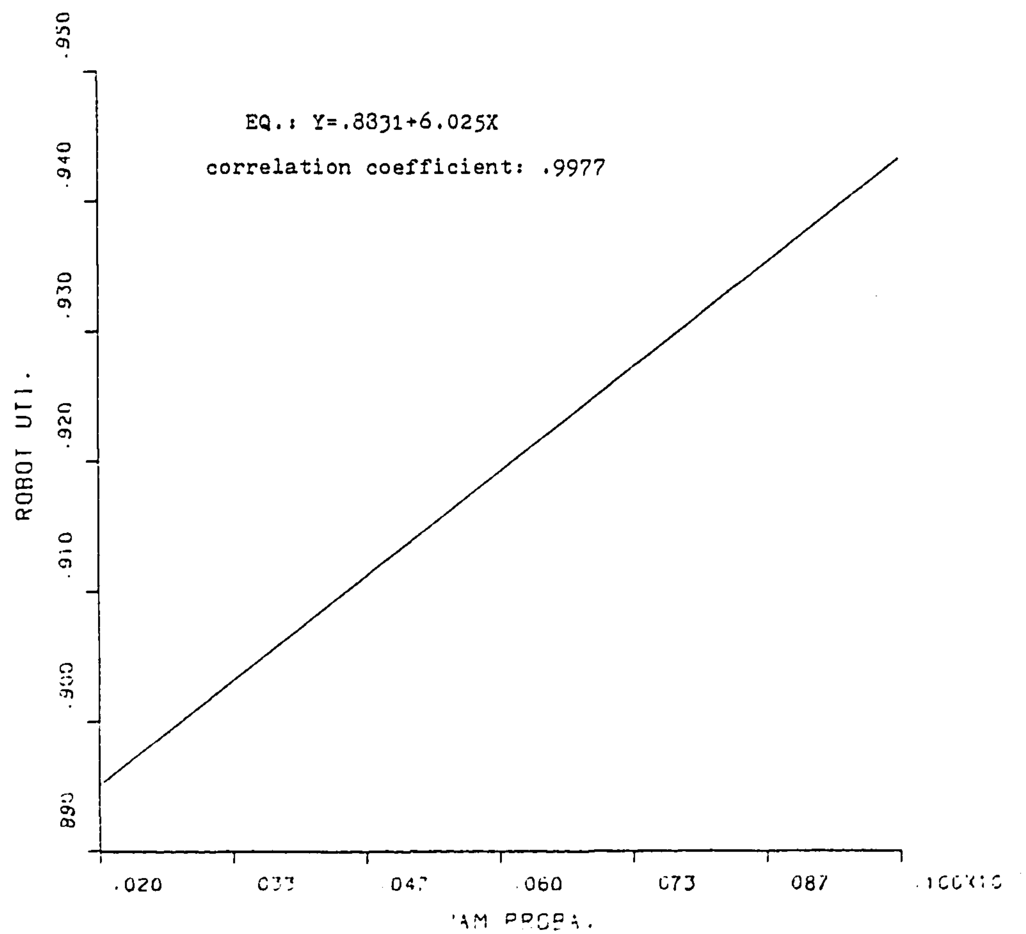


Fig. C

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

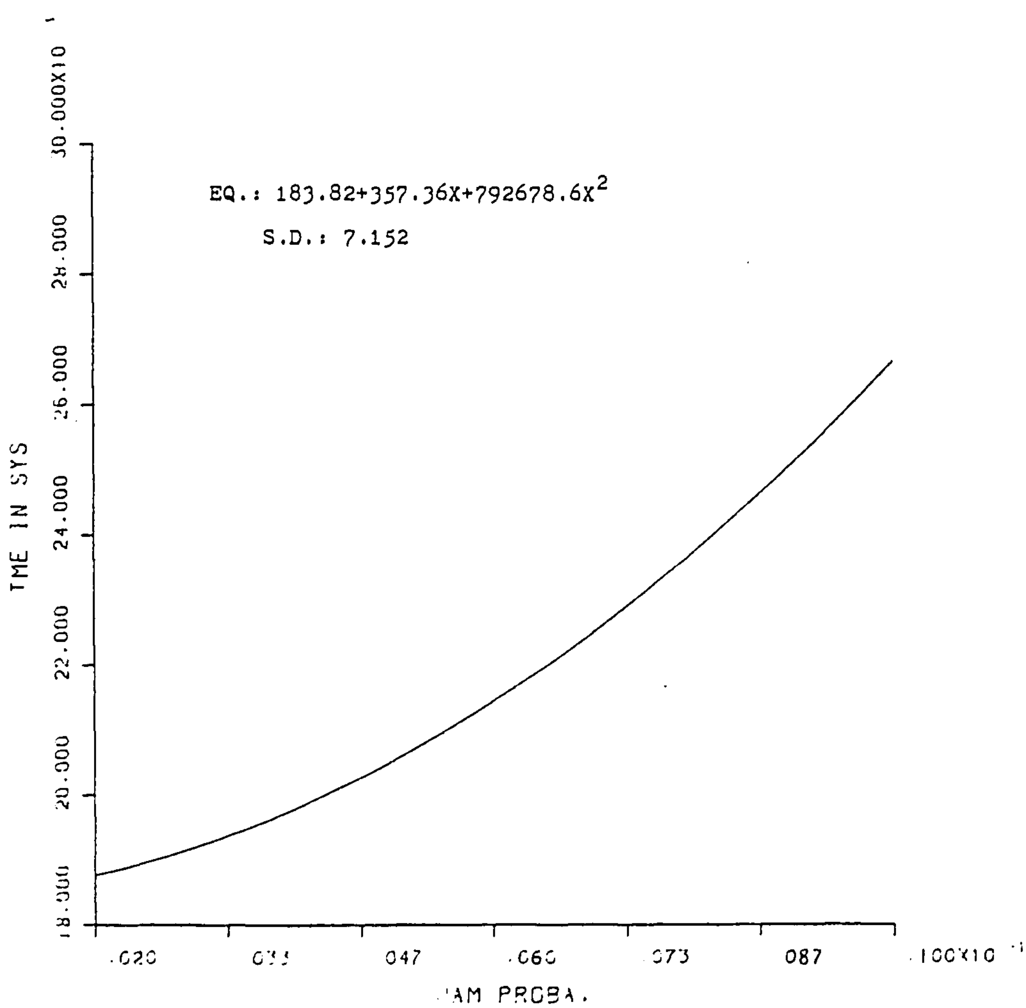


Fig. D

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

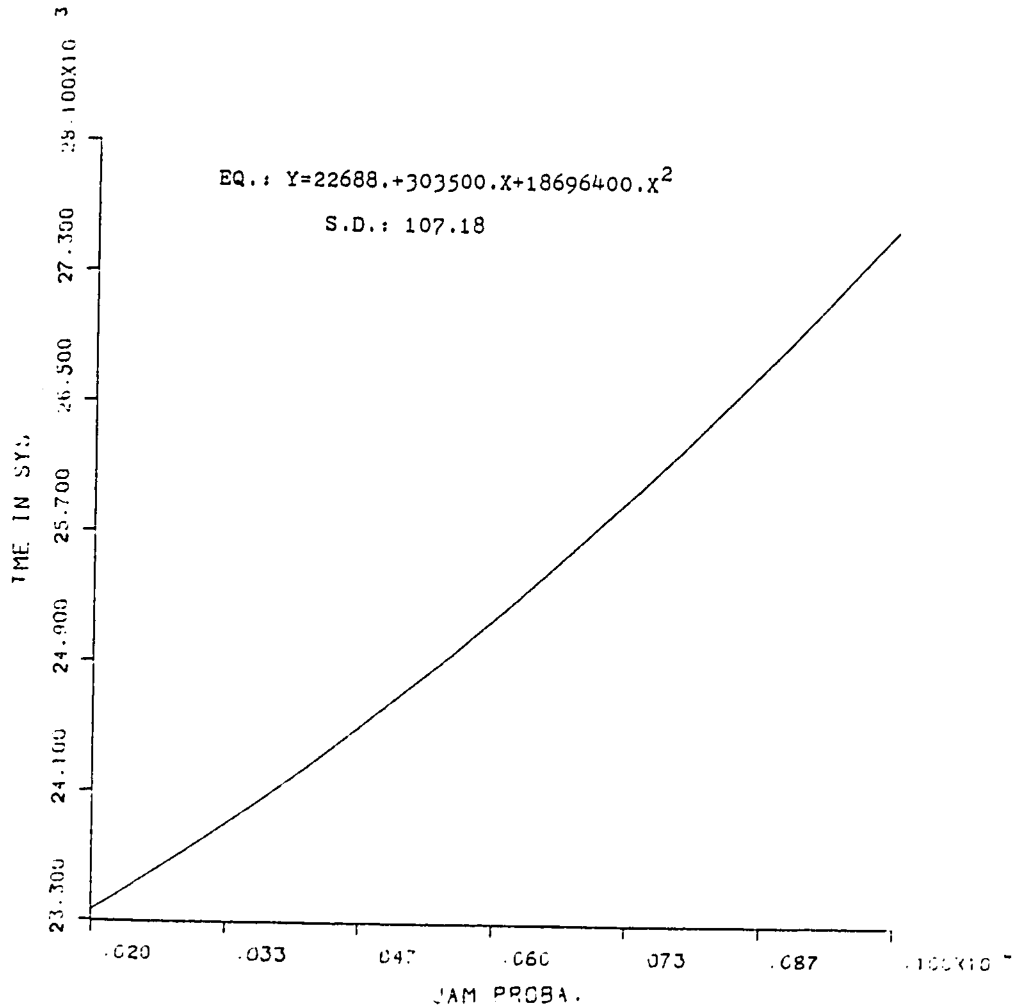


Fig. E

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

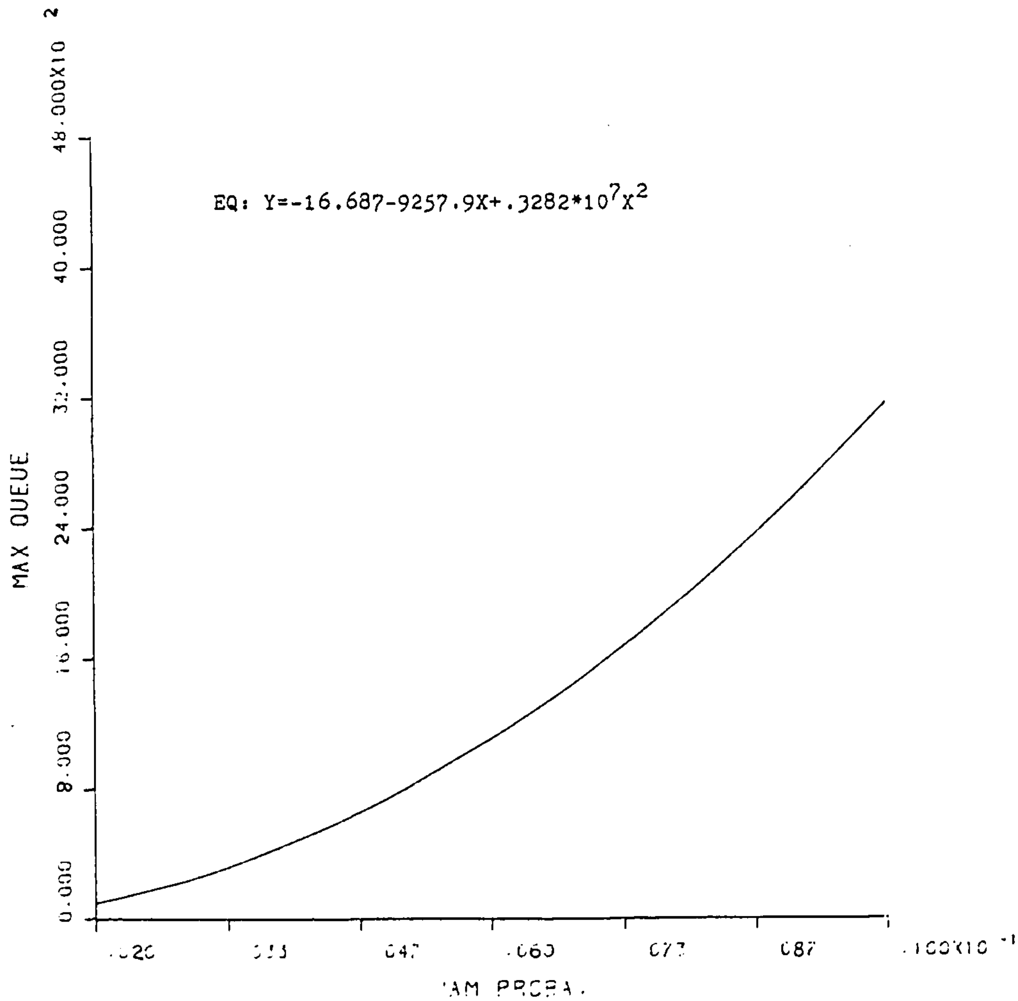
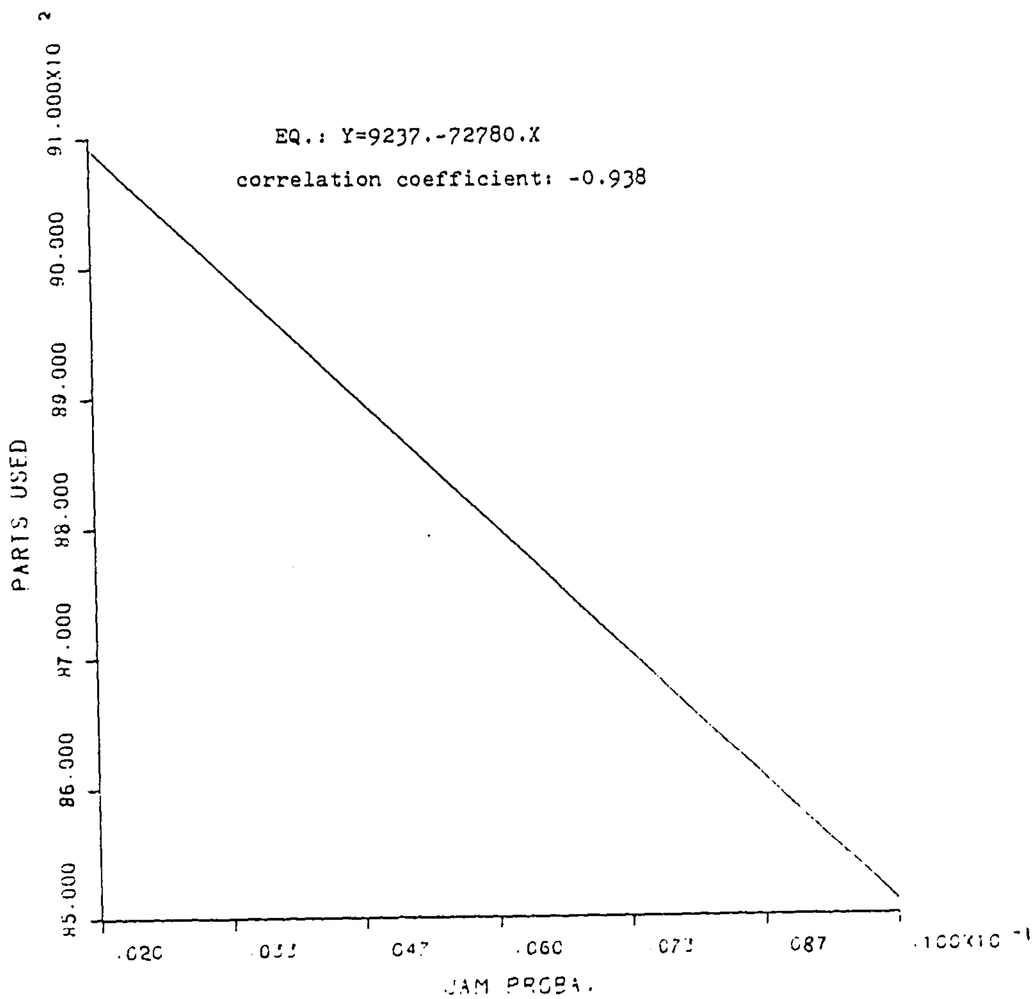


Fig. F

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown



MICRODEX CORRECTION GUIDE (M-9)

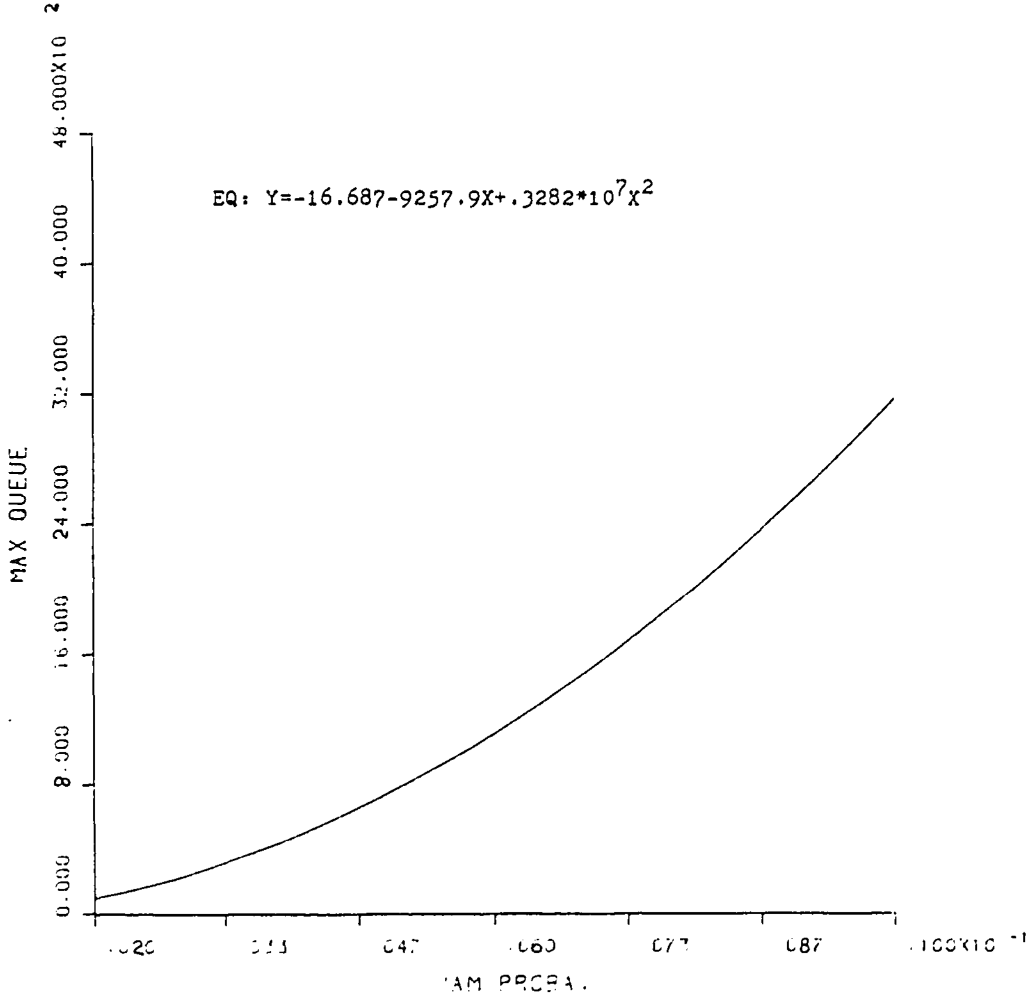
CORRECTION

The preceding document has been re-photographed to assure legibility and its image appears immediately hereafter.

Fig. E

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown



MICRODEX CORRECTION GUIDE (M-9)

CORRECTION

The preceding document has been re-photographed to assure legibility and its image appears immediately hereafter.

KP 23000

REMINGTON RAND
OFFICE SYSTEMS DIVISION

Fig. A

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

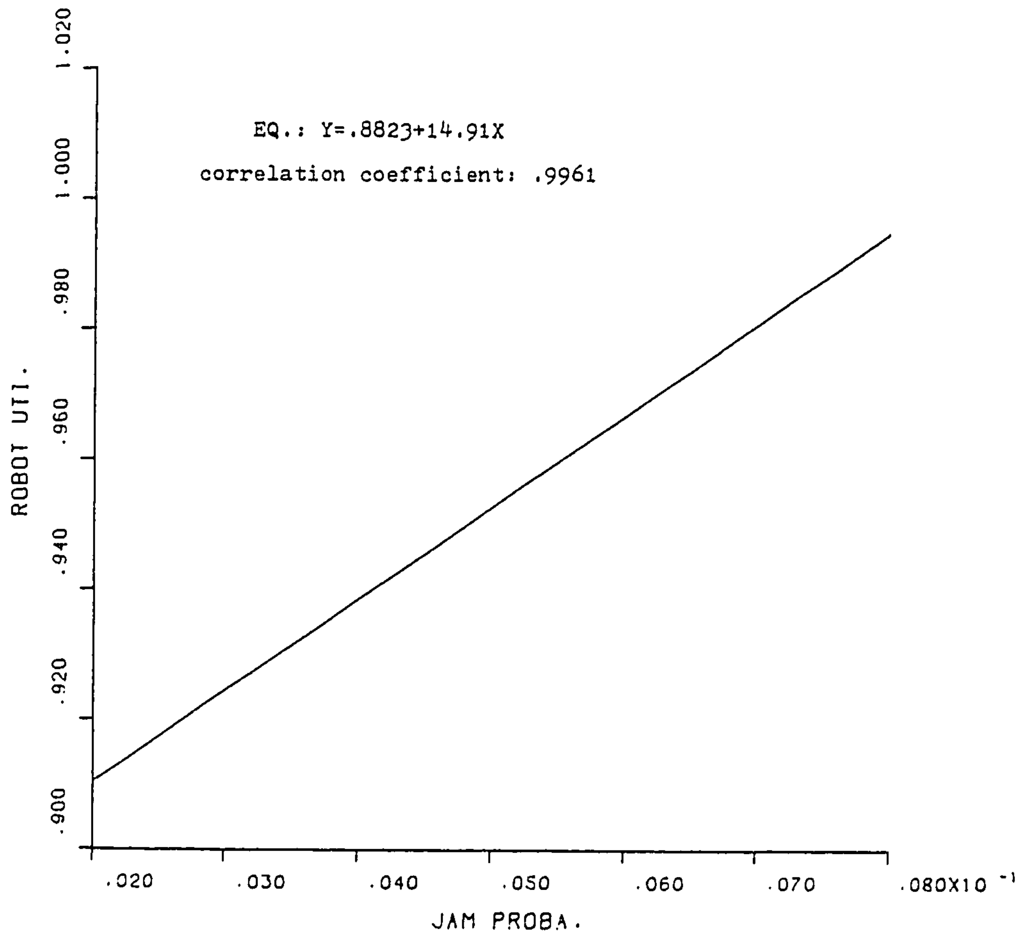


Fig. A

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

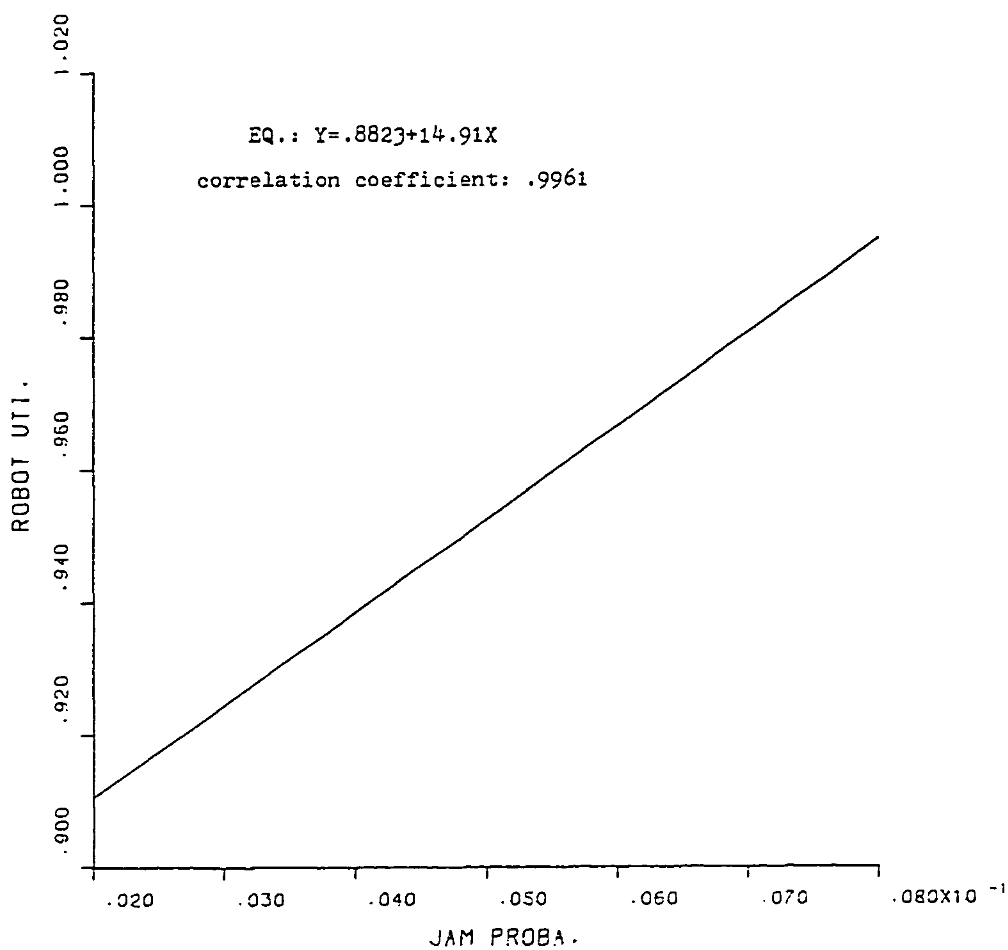


Fig. B

Assembly Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

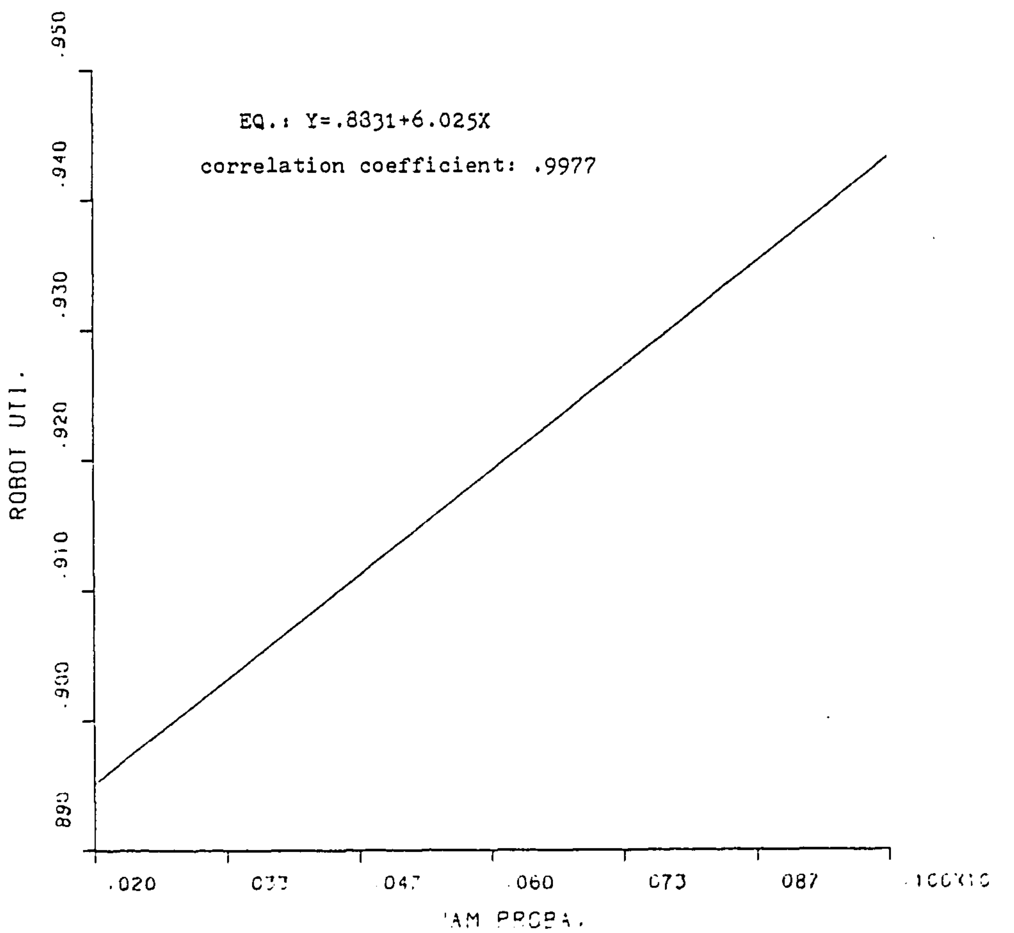


Fig. B

Assembly Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

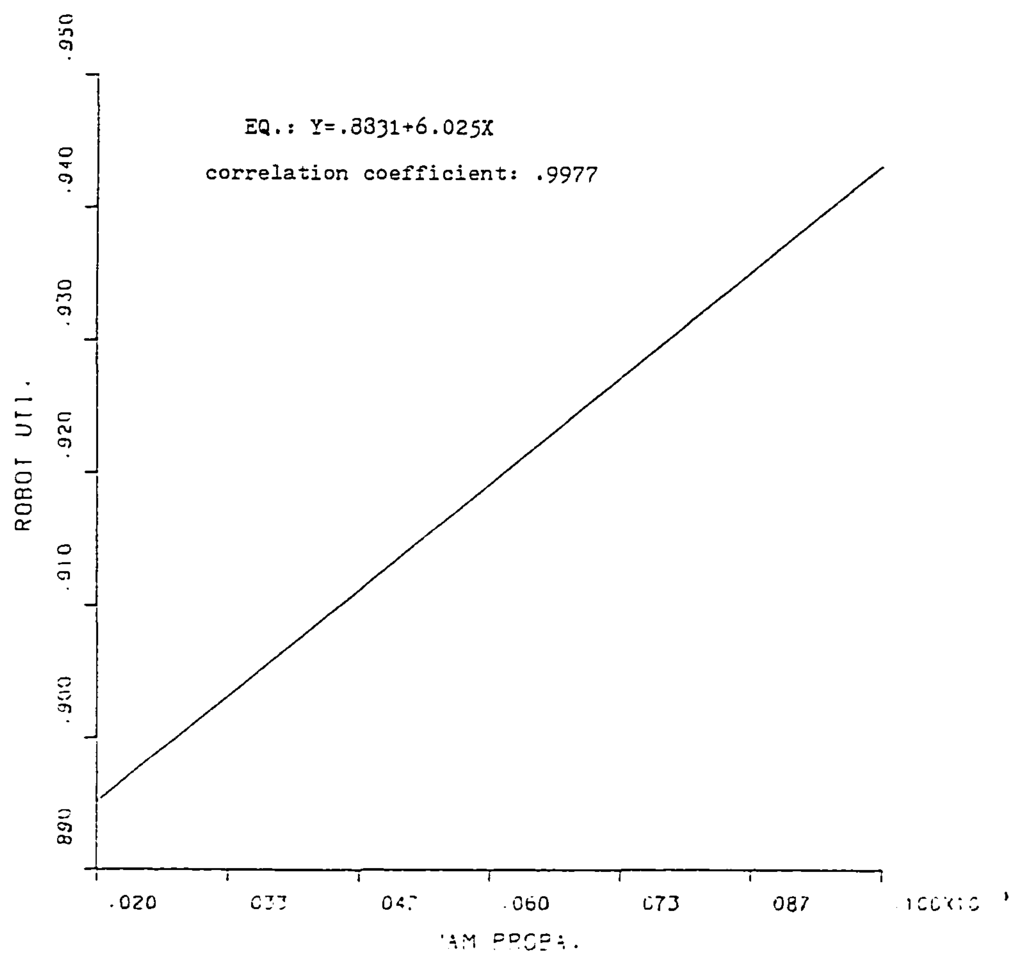


Fig. C

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

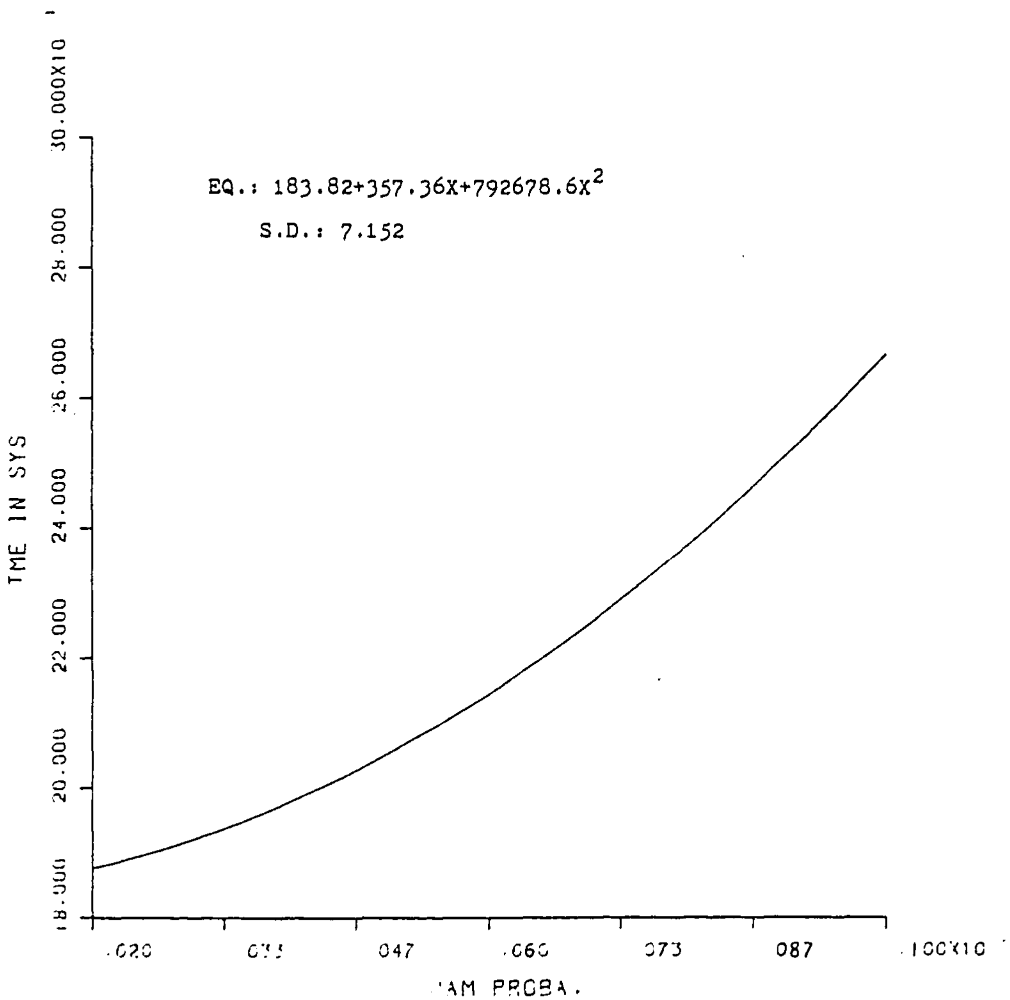


Fig. C

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

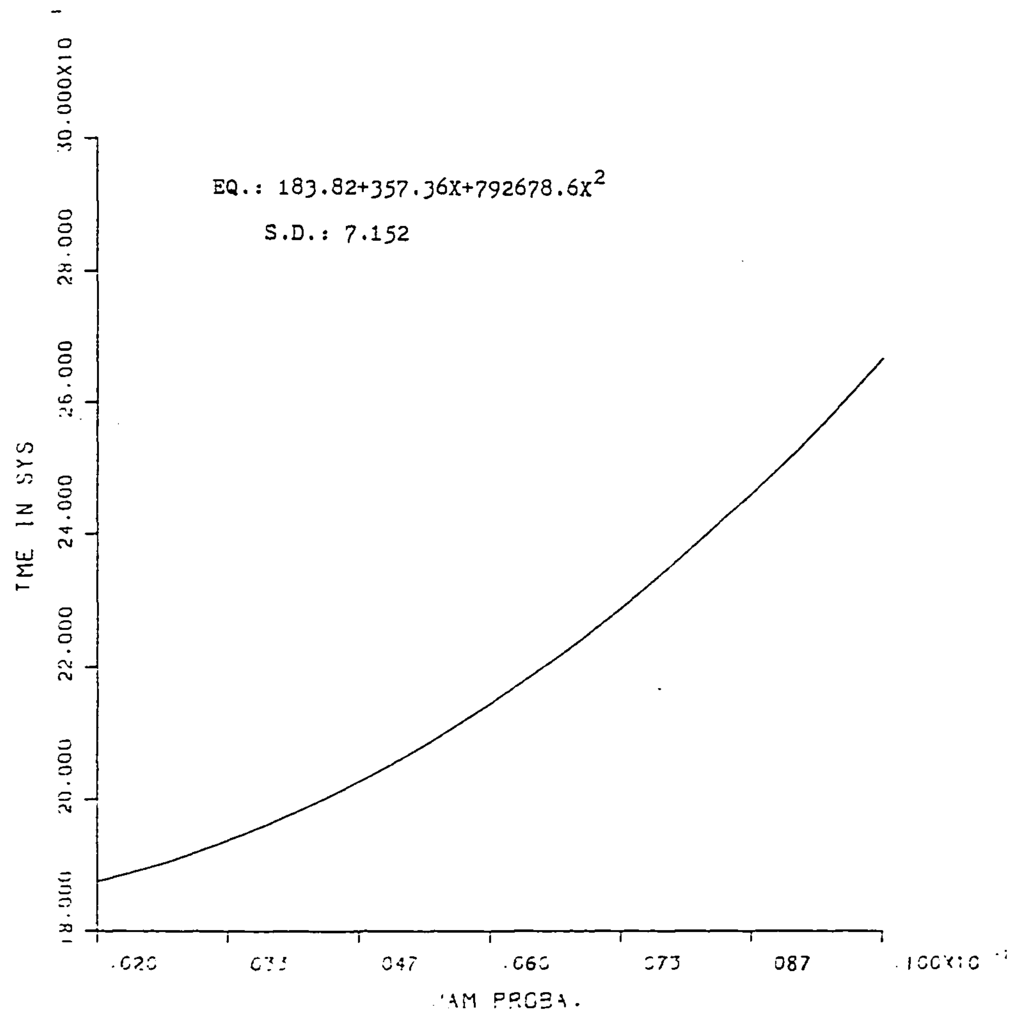


Fig. D

Palletizing Line

time between successive pallets in : 200 secconds
time needed for solving the jam : 200 seconds
no robot breakdown

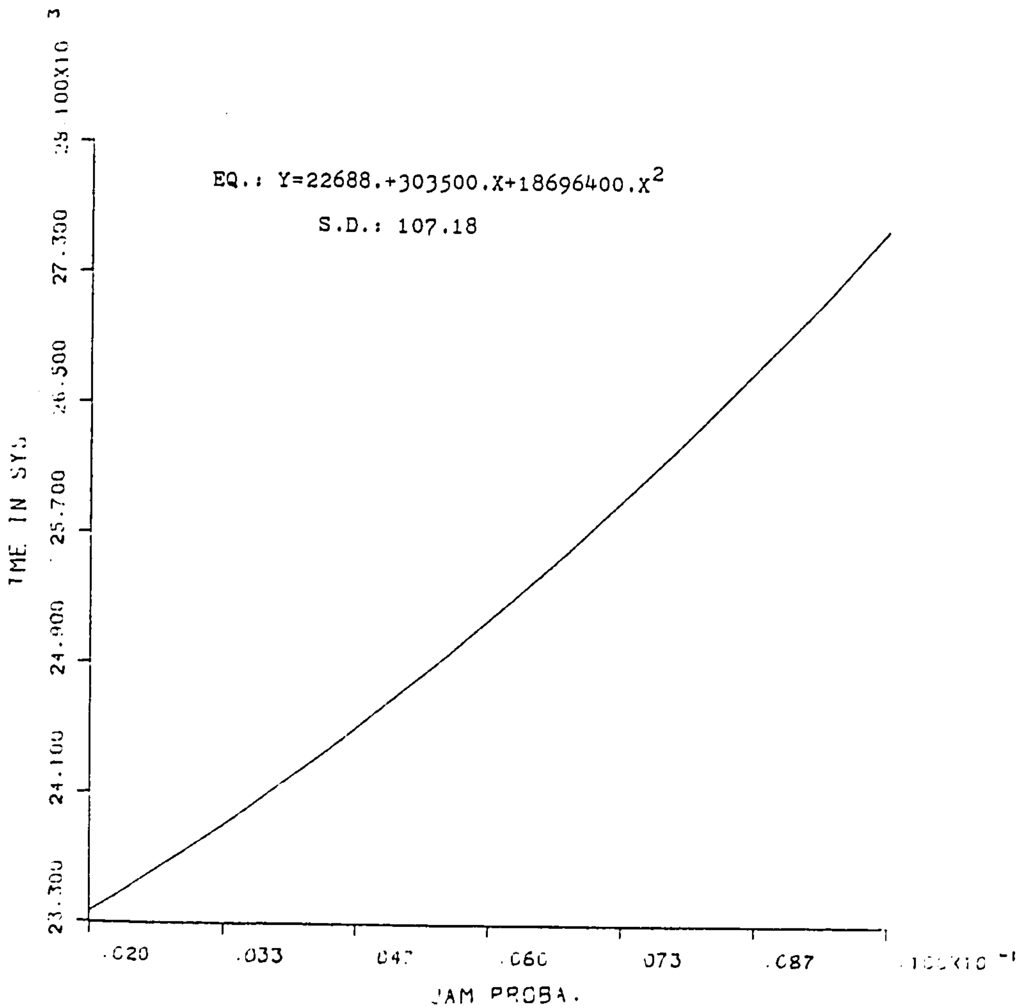


Fig. D

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

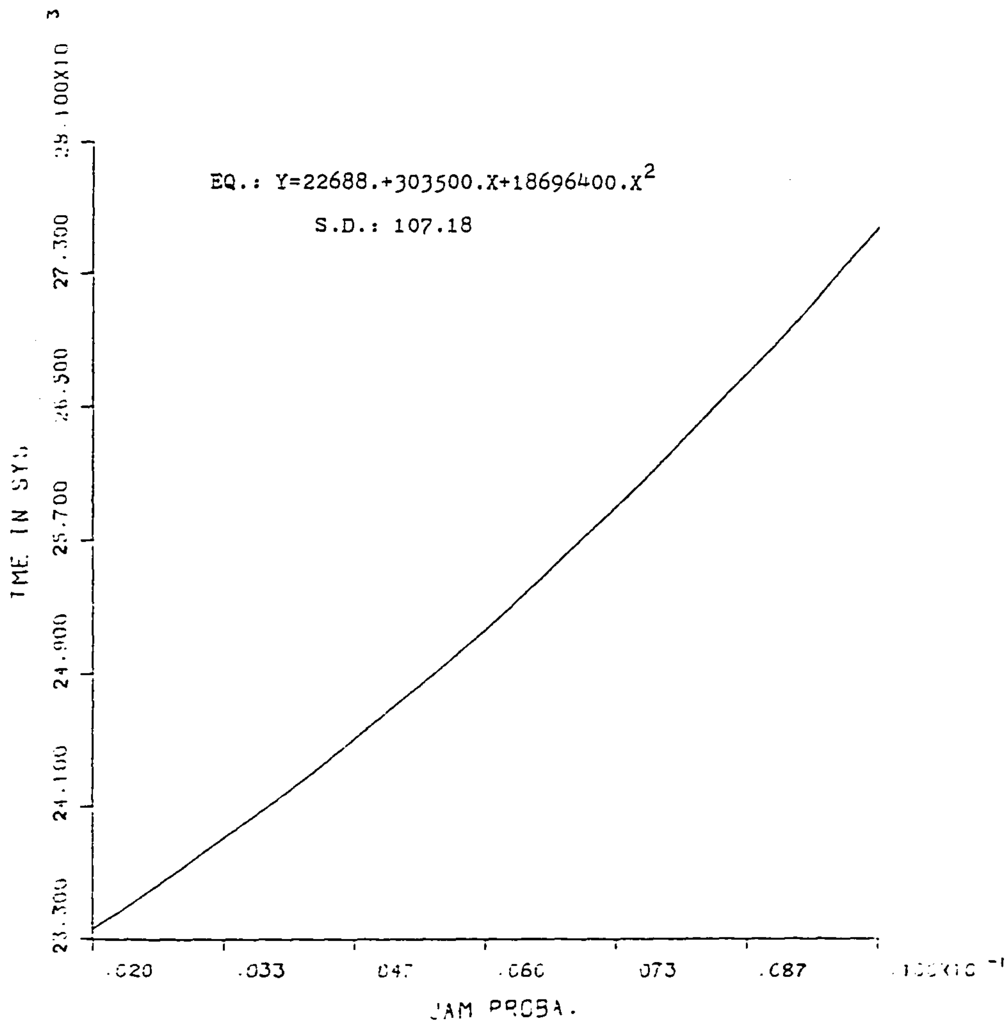


Fig. E

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

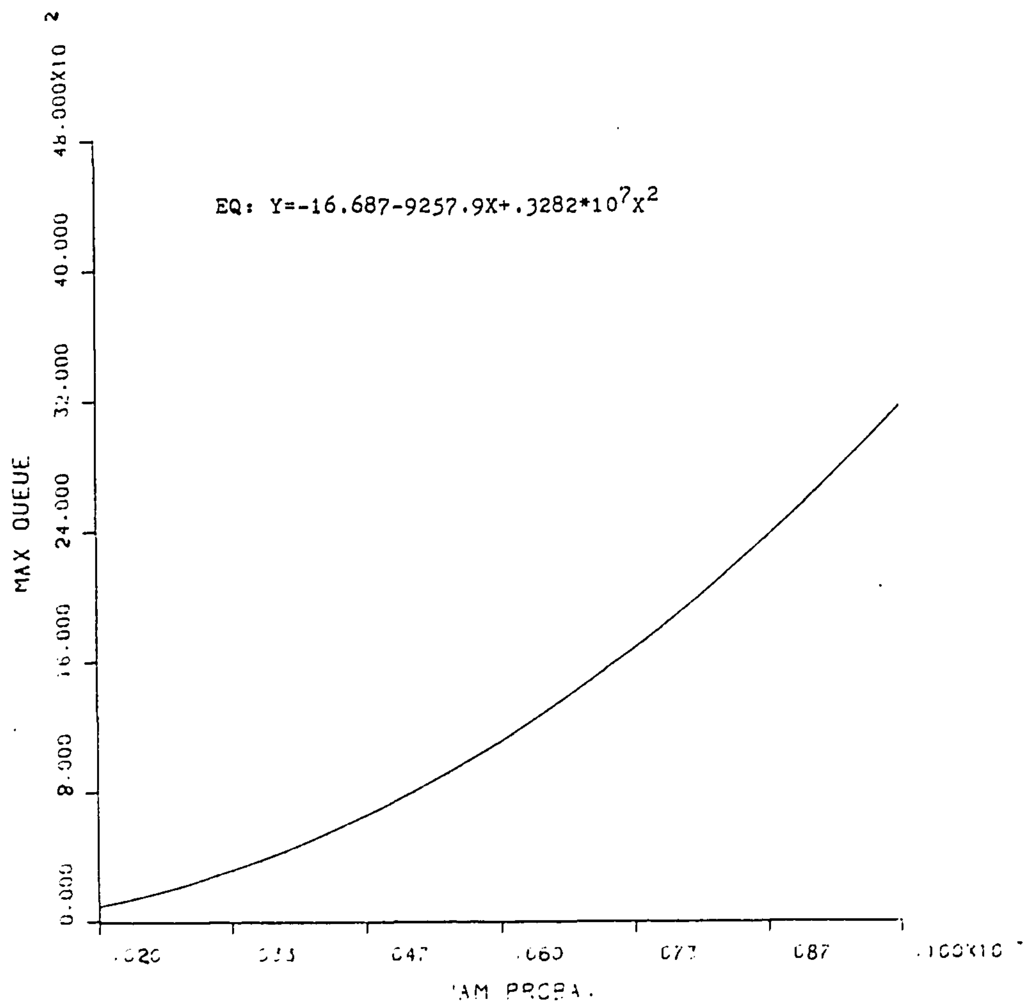


Fig. E

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

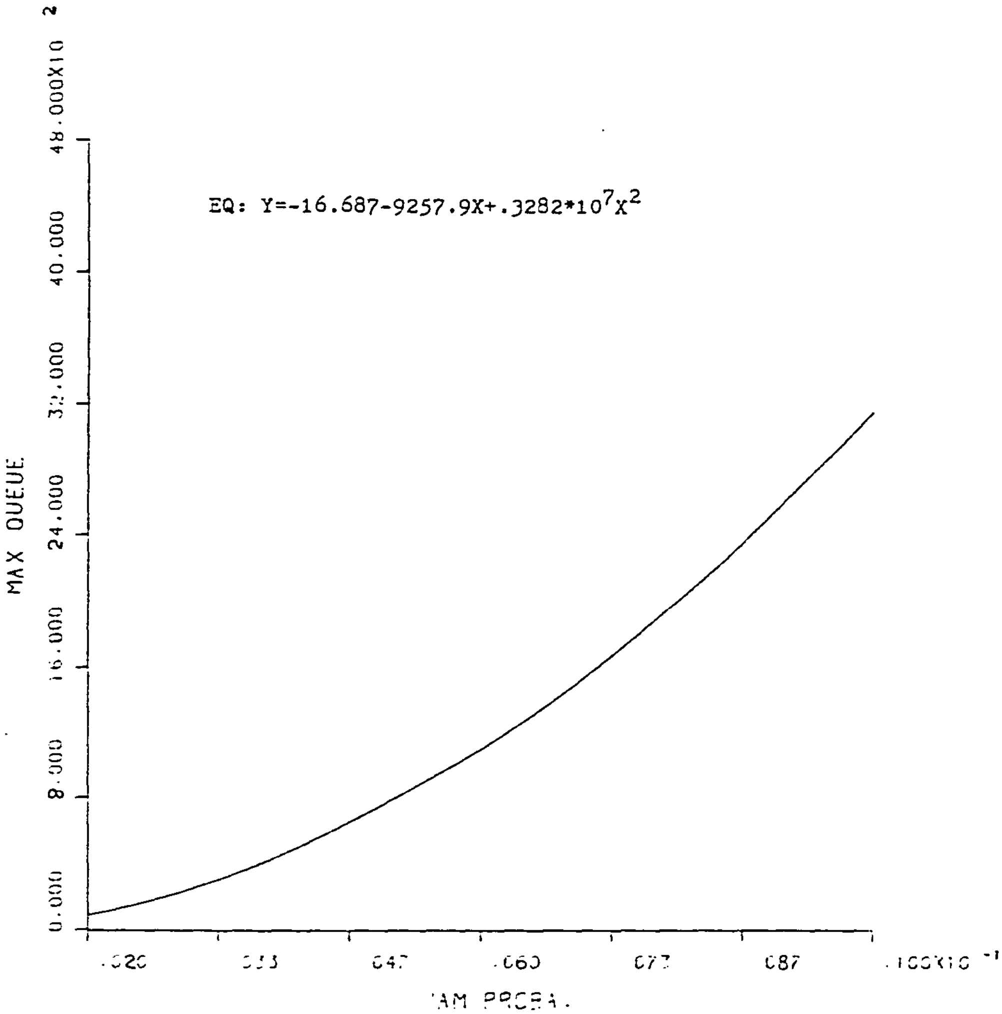


Fig. F

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

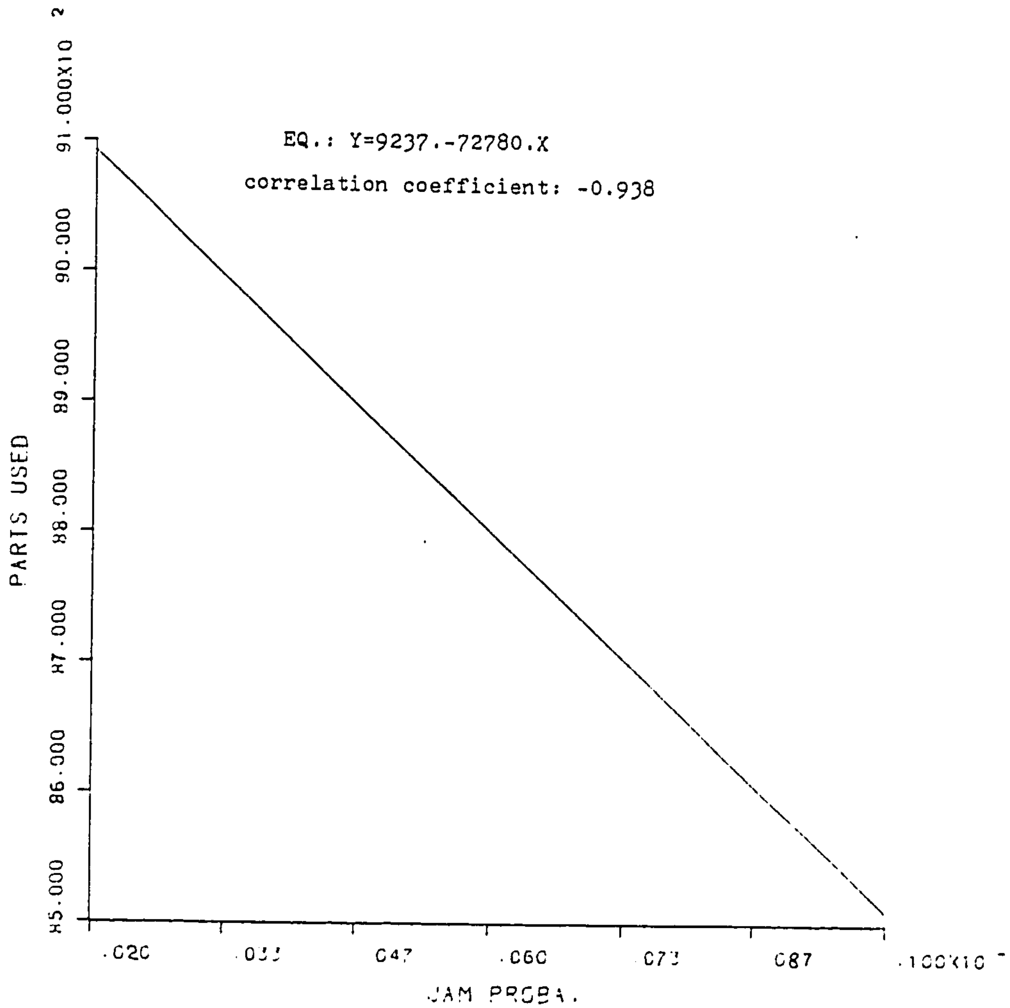


Fig. F

Palletizing Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
no robot breakdown

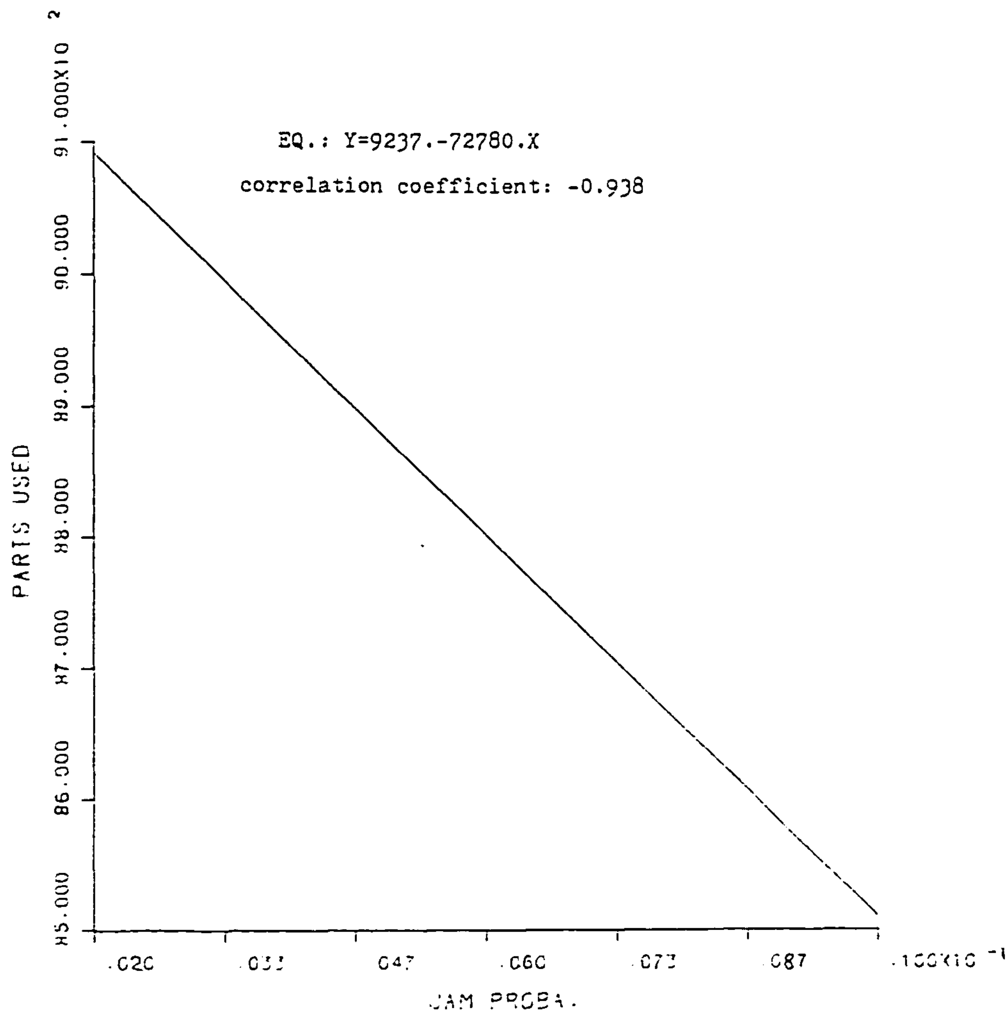


Fig. G

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

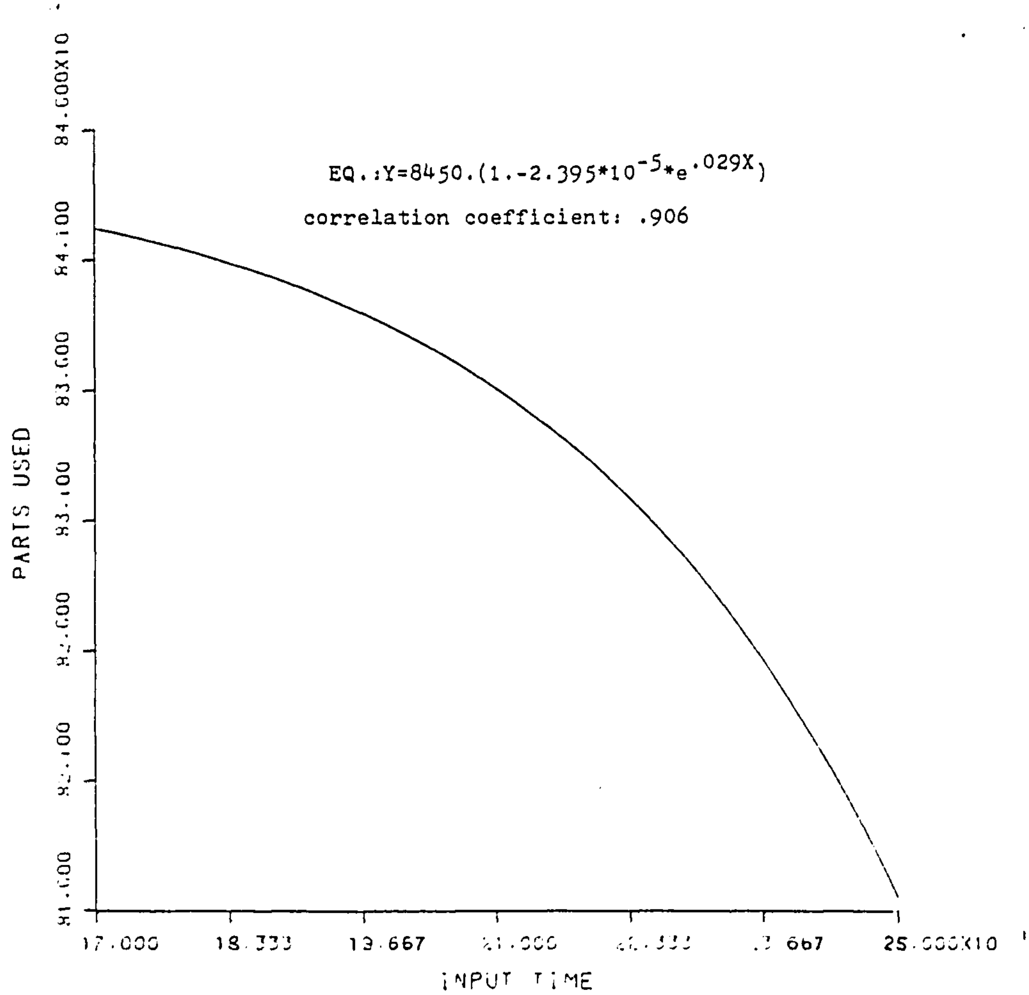


Fig. G

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

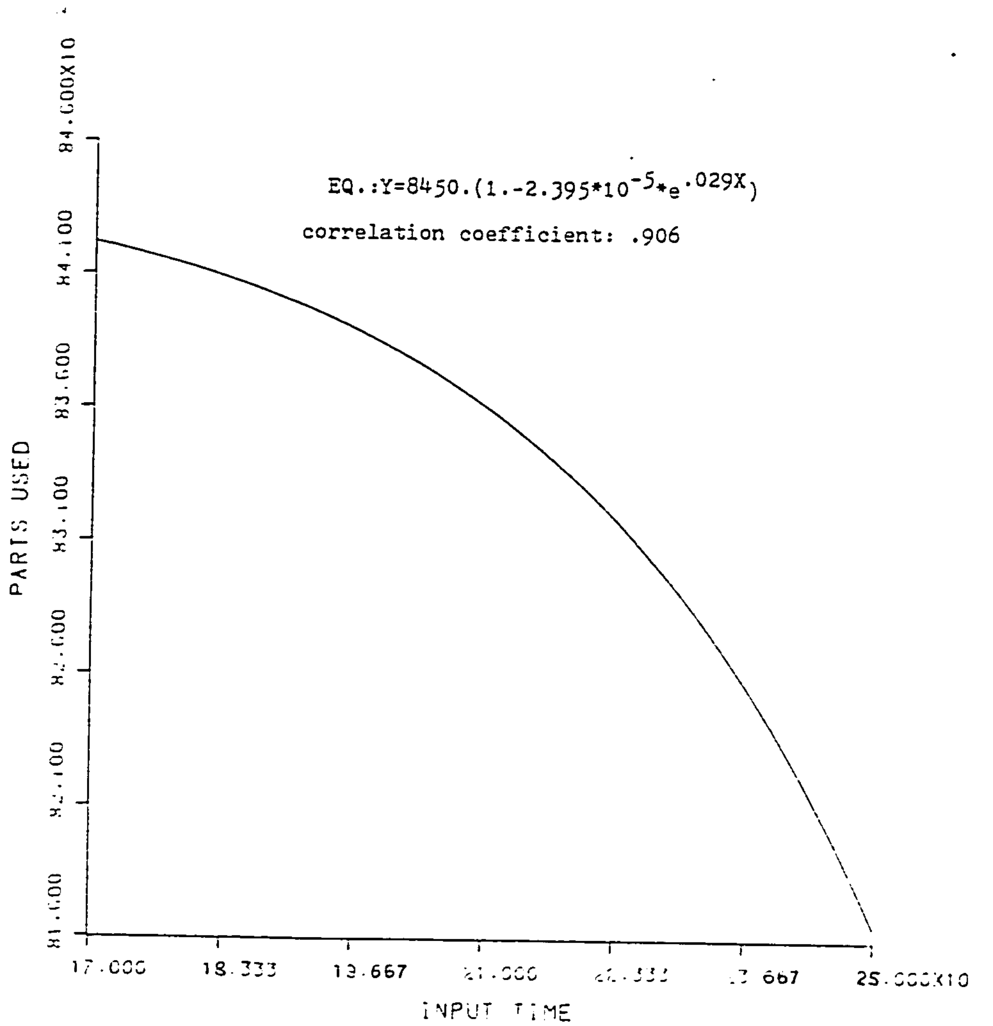


Fig. H

Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

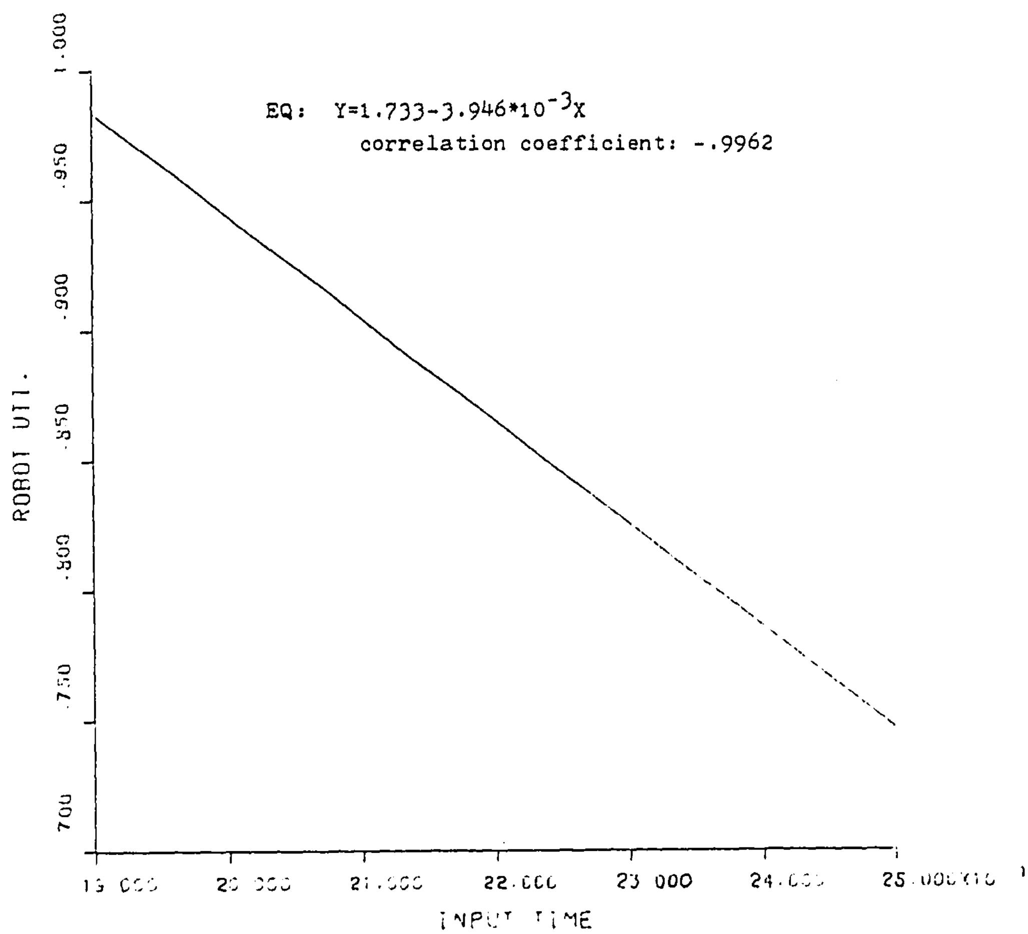


Fig. H

Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

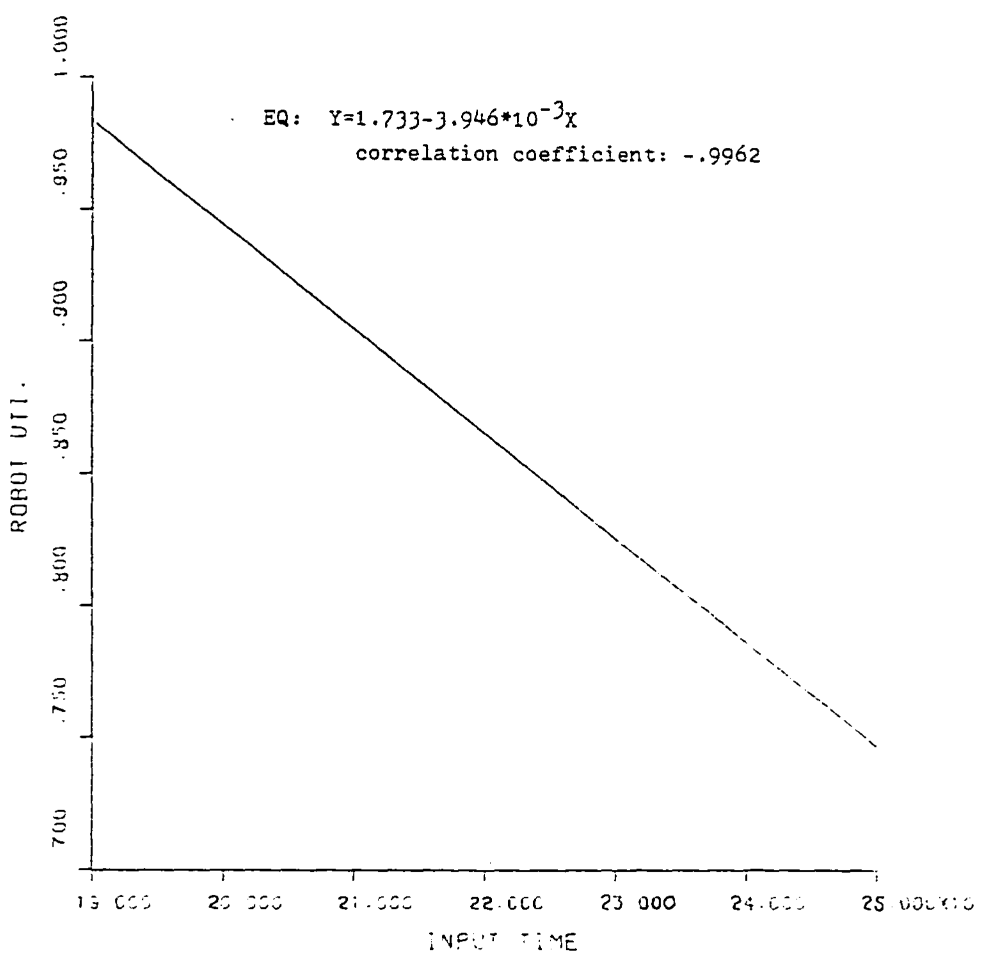


Fig. I

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

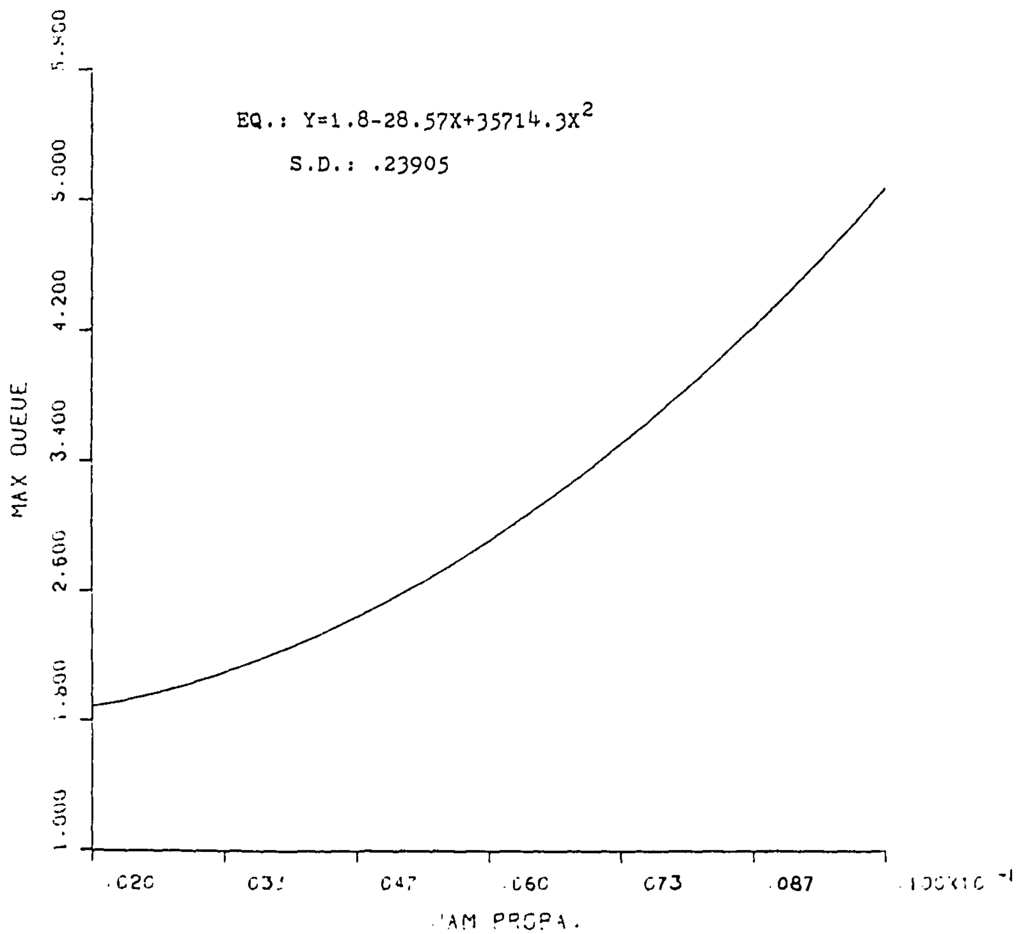


Fig. I

Assembly Line

time needed for solving the jam : 200 seconds
time between successive pallets in : 200 seconds
no robot breakdown

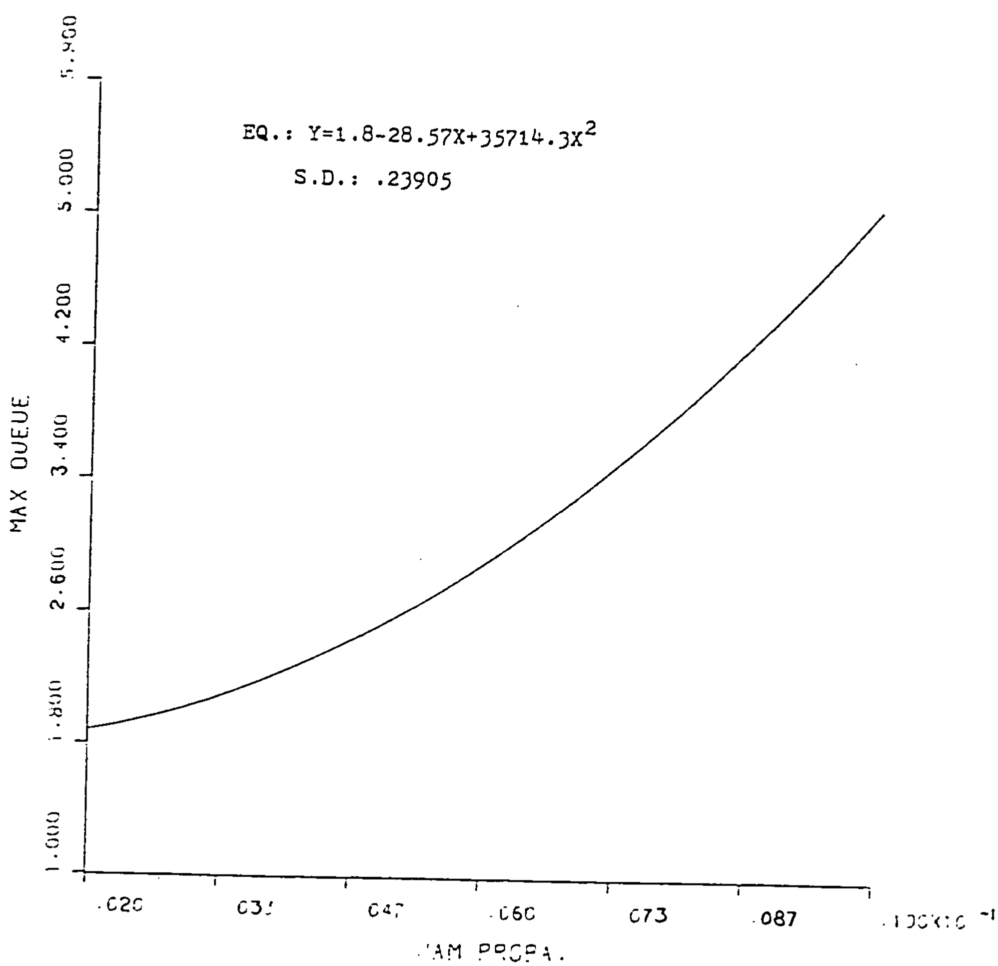


Fig. . J

'Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

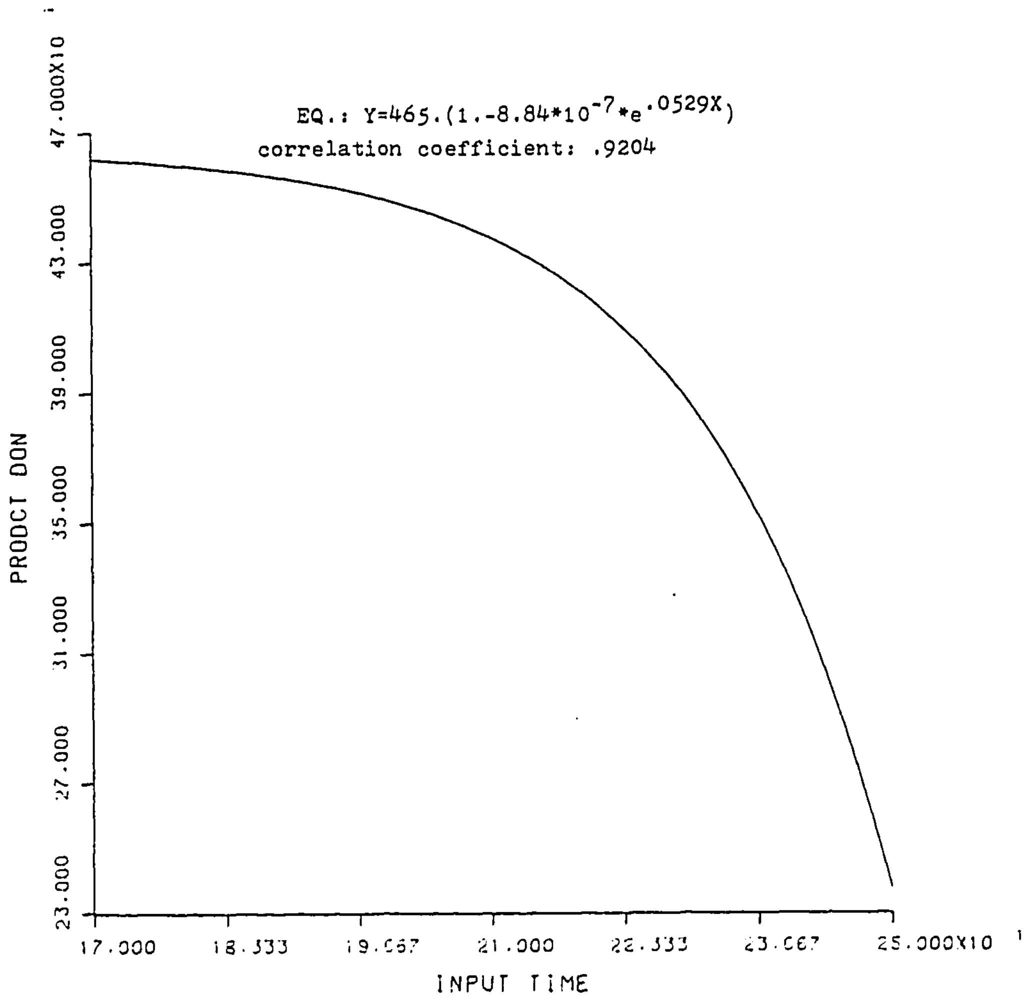


Fig. .J

Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

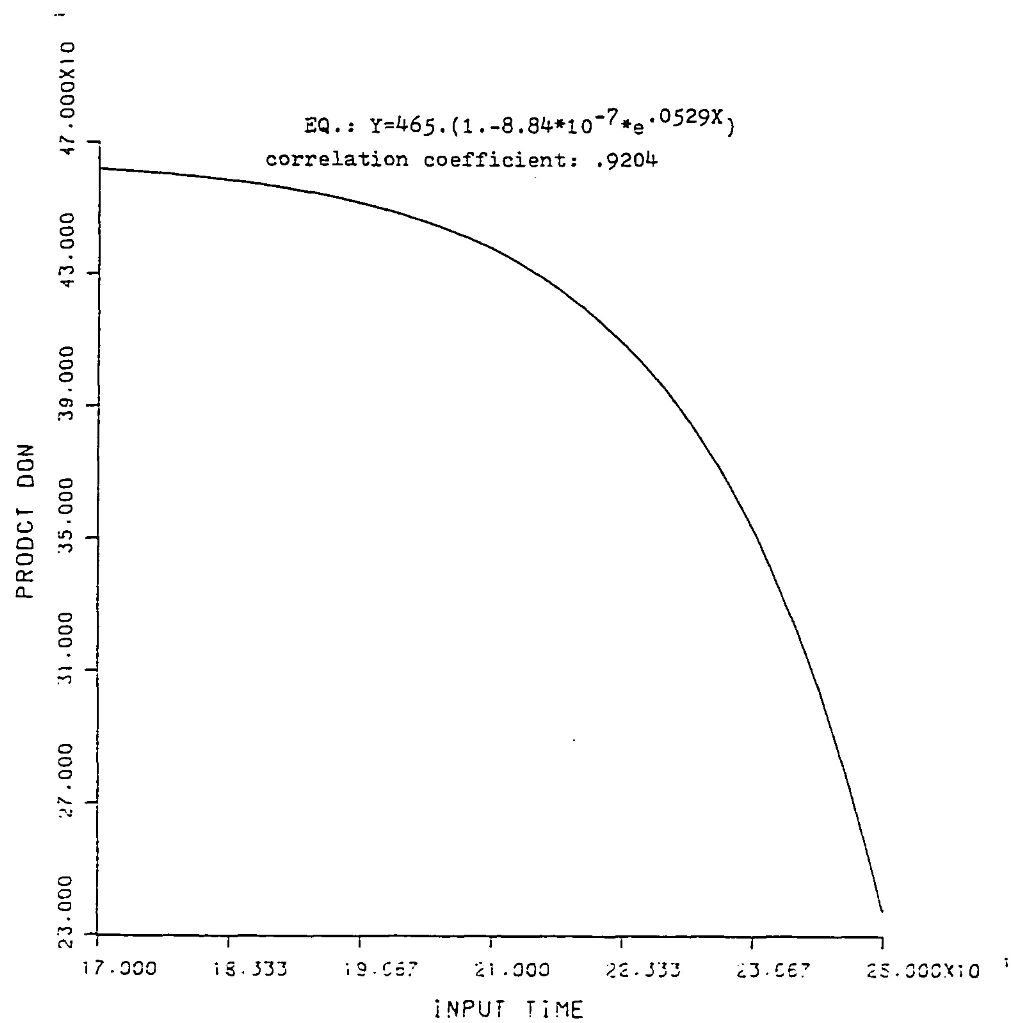


Fig. K

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

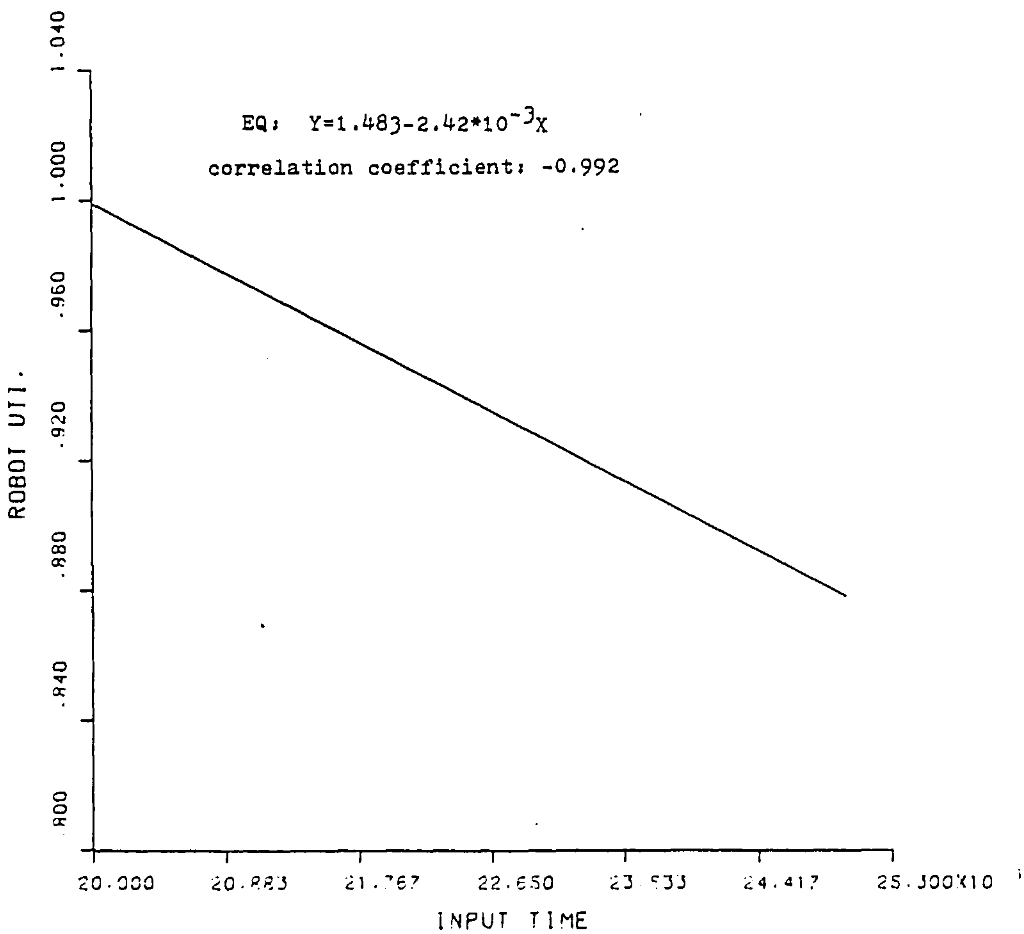


Fig. K .

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

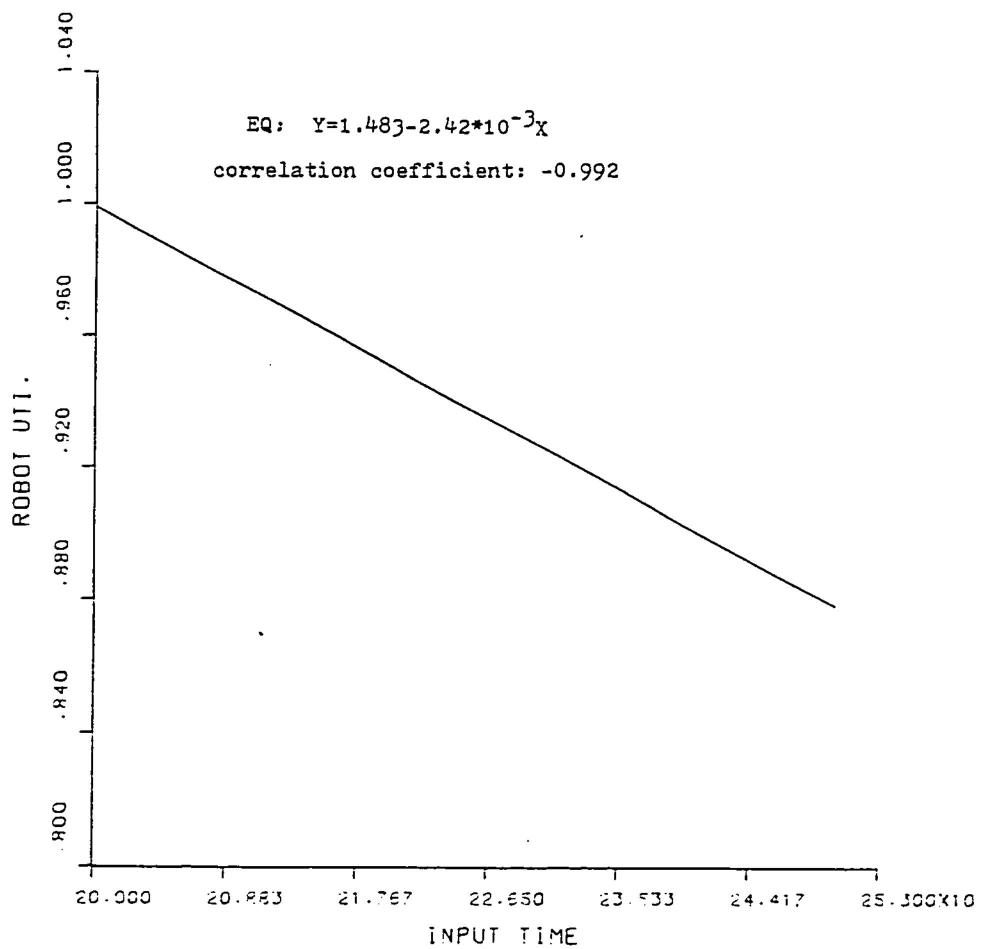


Fig. L

Assembly Line

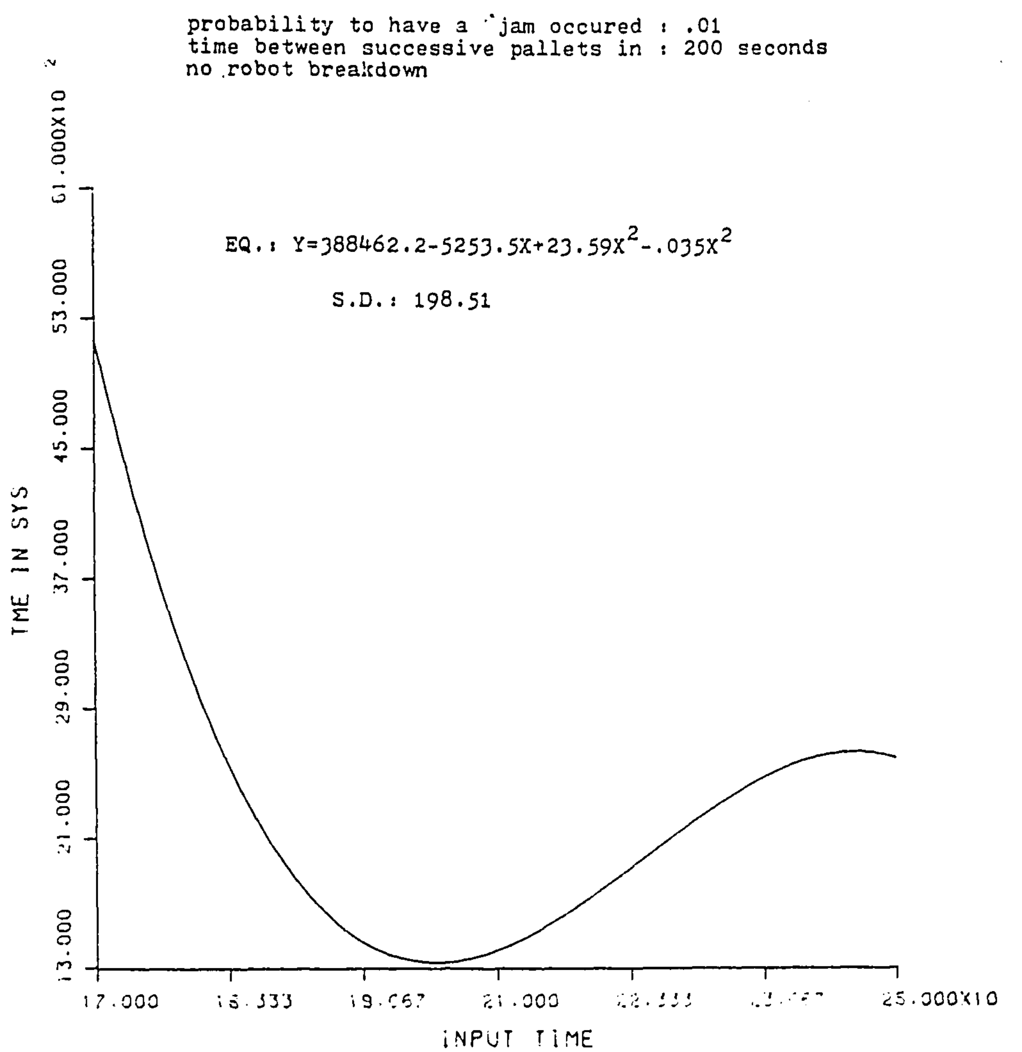


Fig. L

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

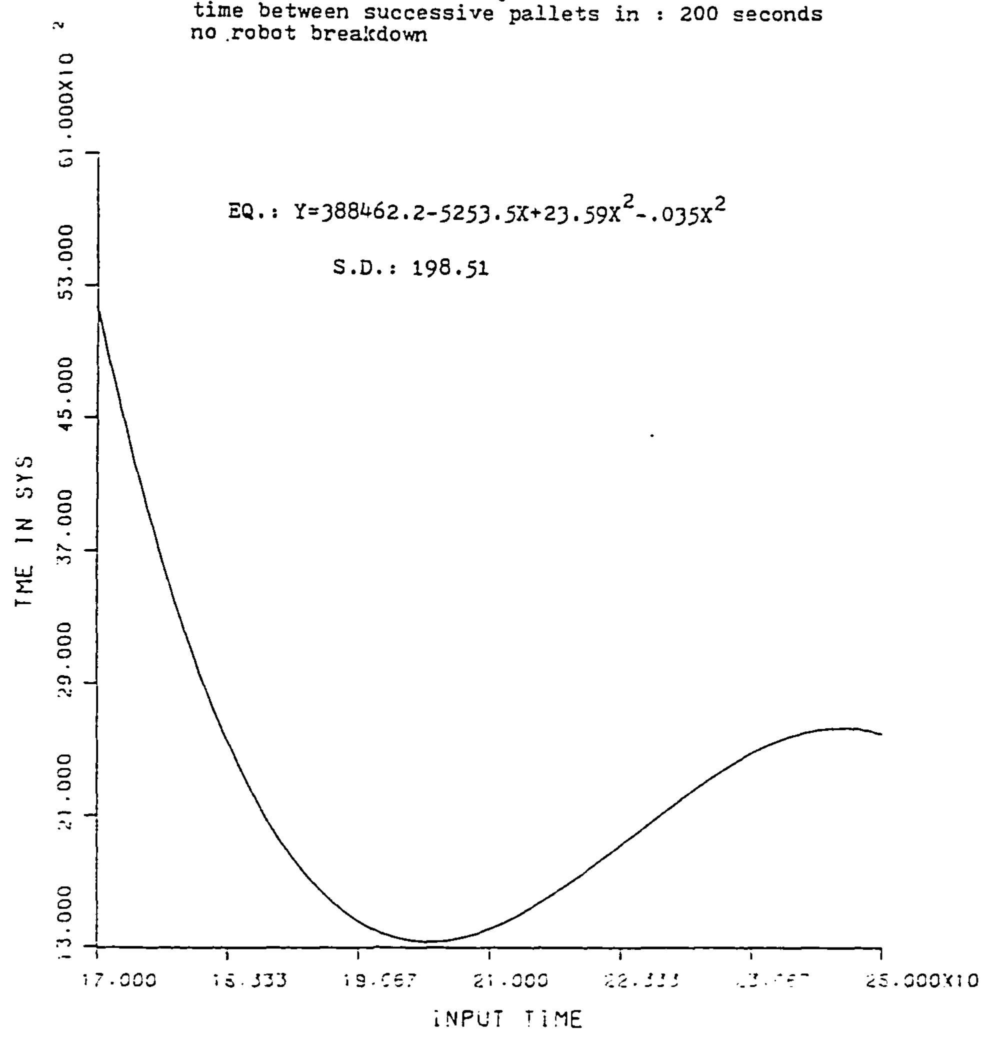


Fig. M

Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

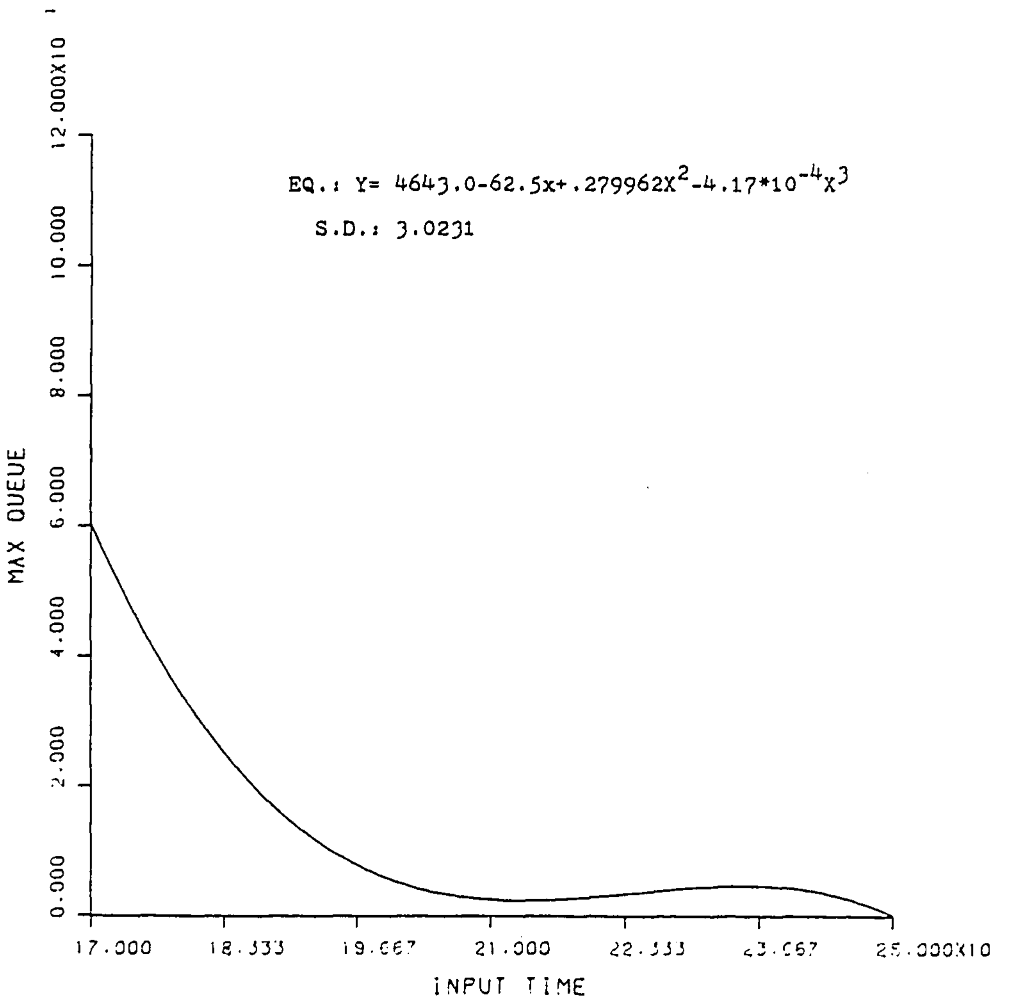


Fig. M

Assembly Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

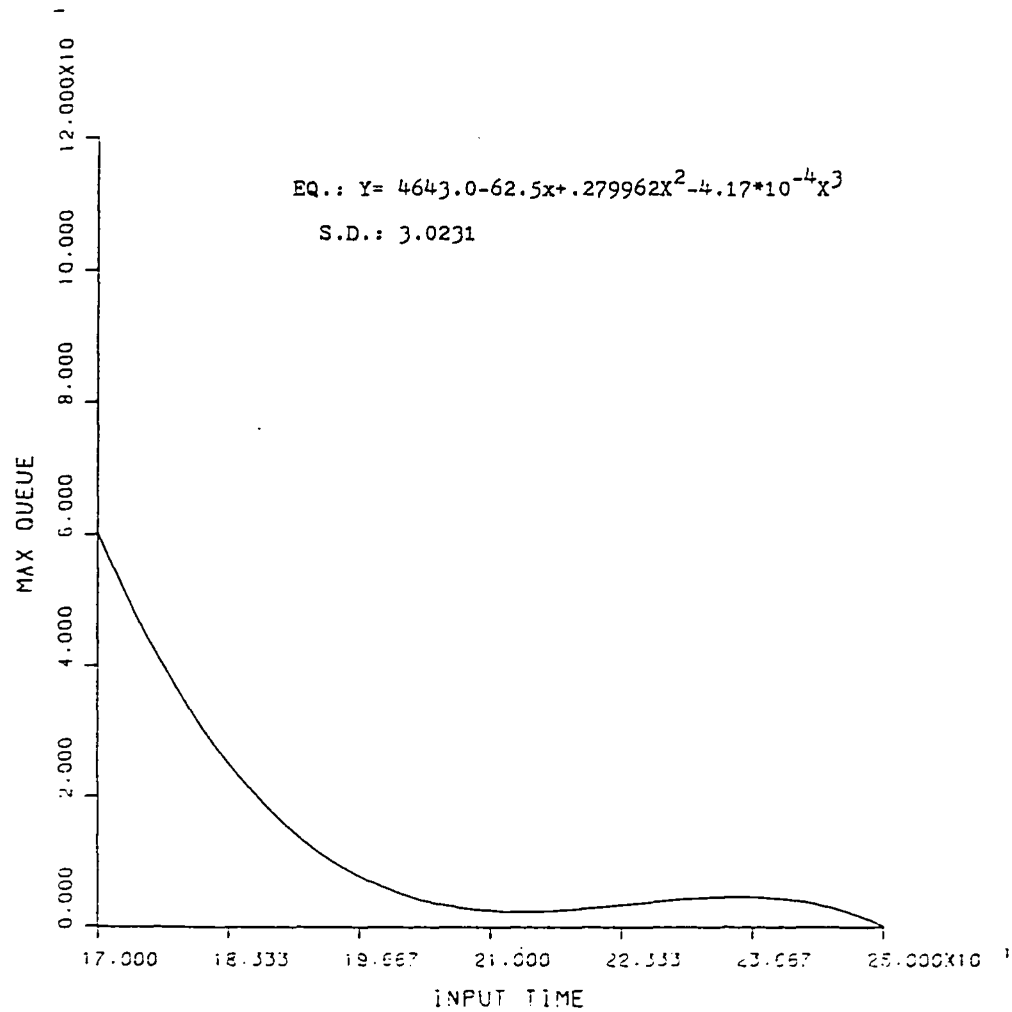


Fig. N

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

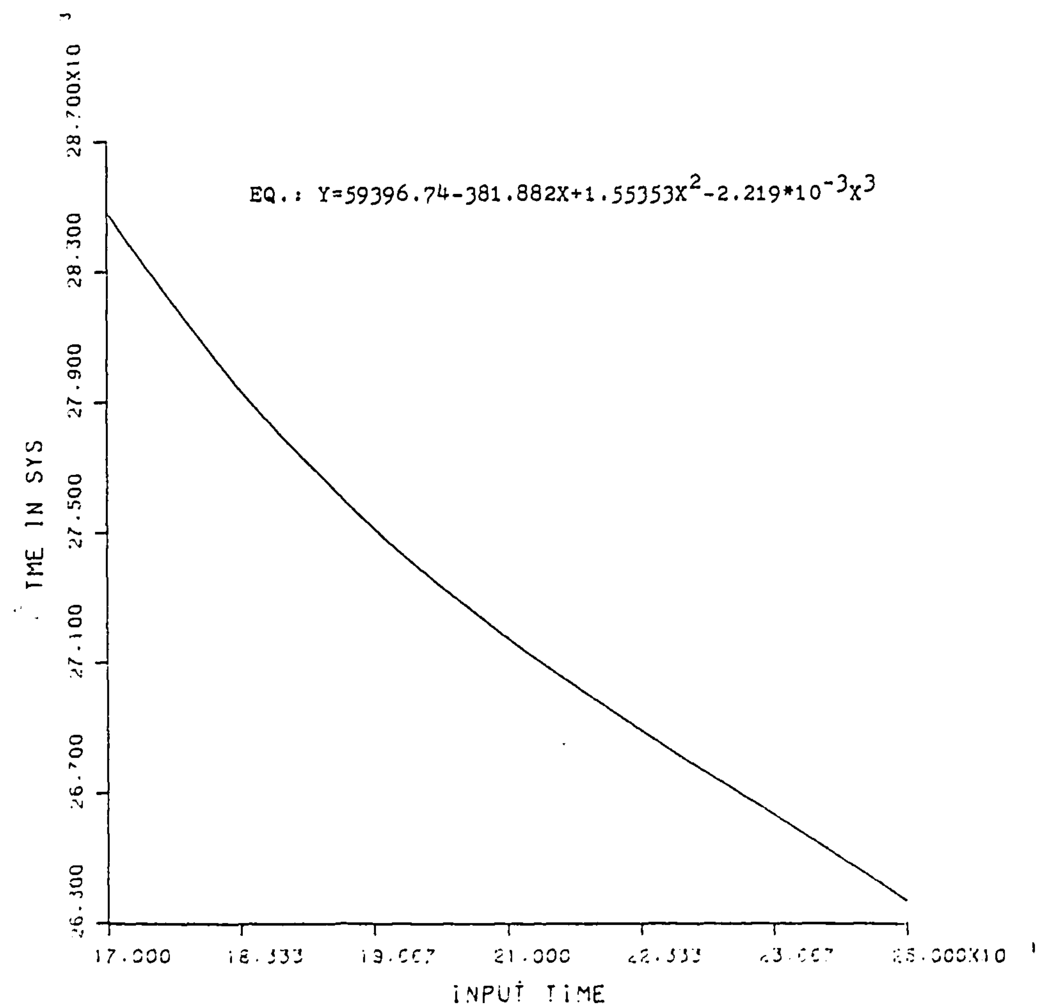


Fig. N

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

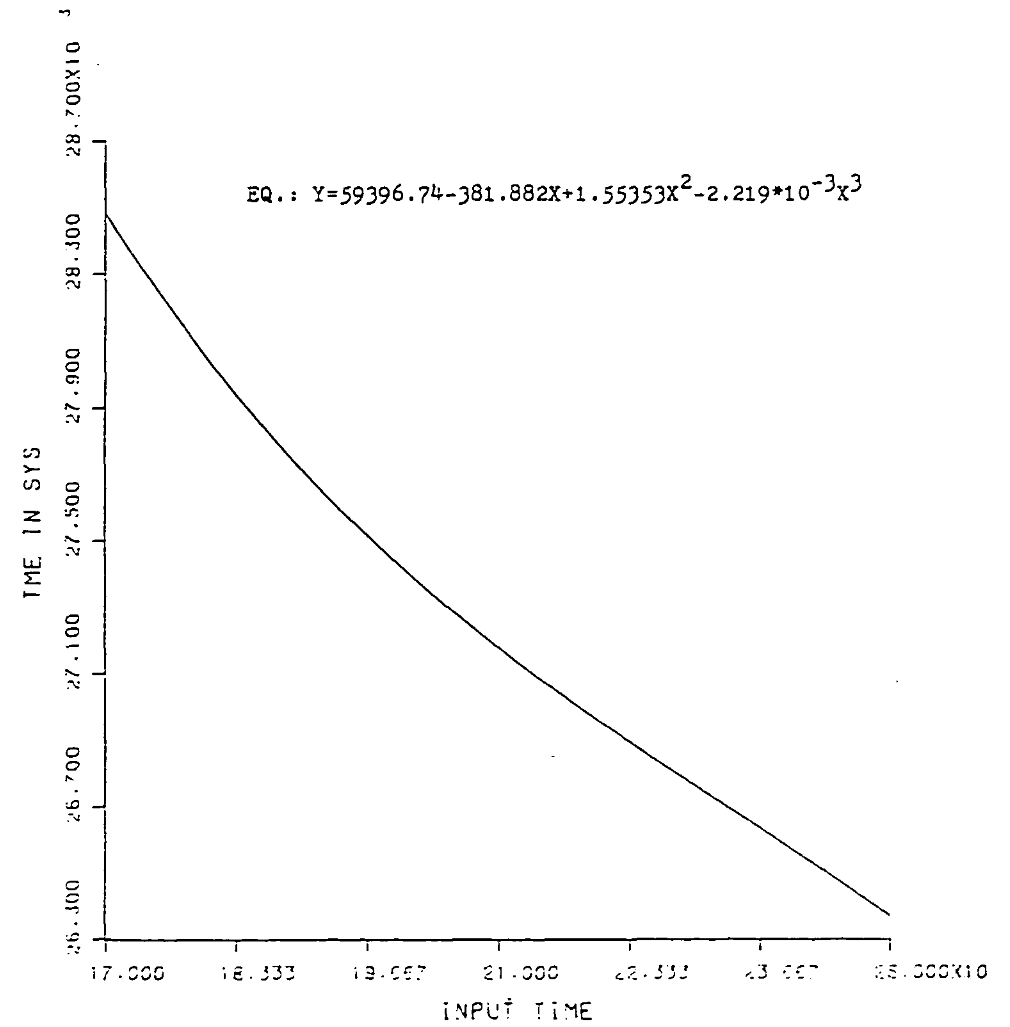


Fig. 0

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

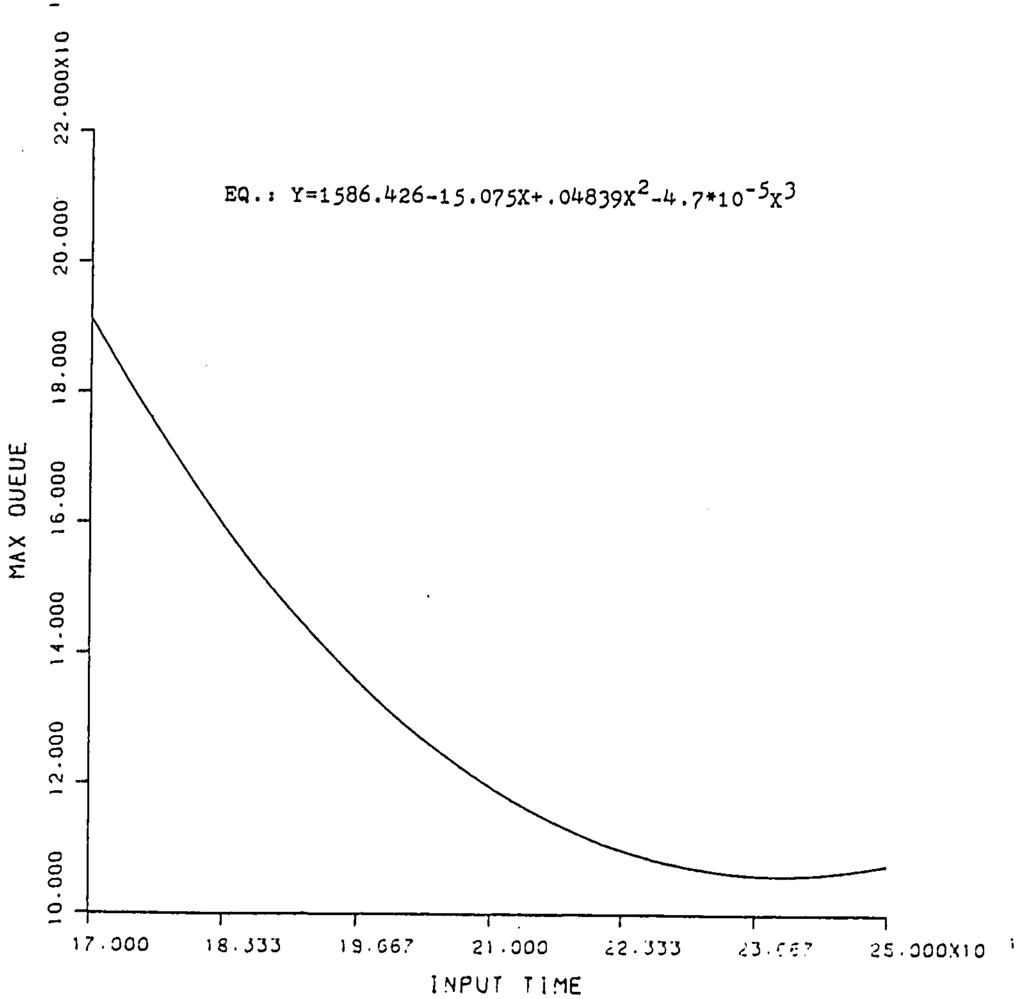


Fig. 0

Palletizing Line

probability to have a jam occured : .01
time needed for solving the jam : 200 seconds
no robot breakdown

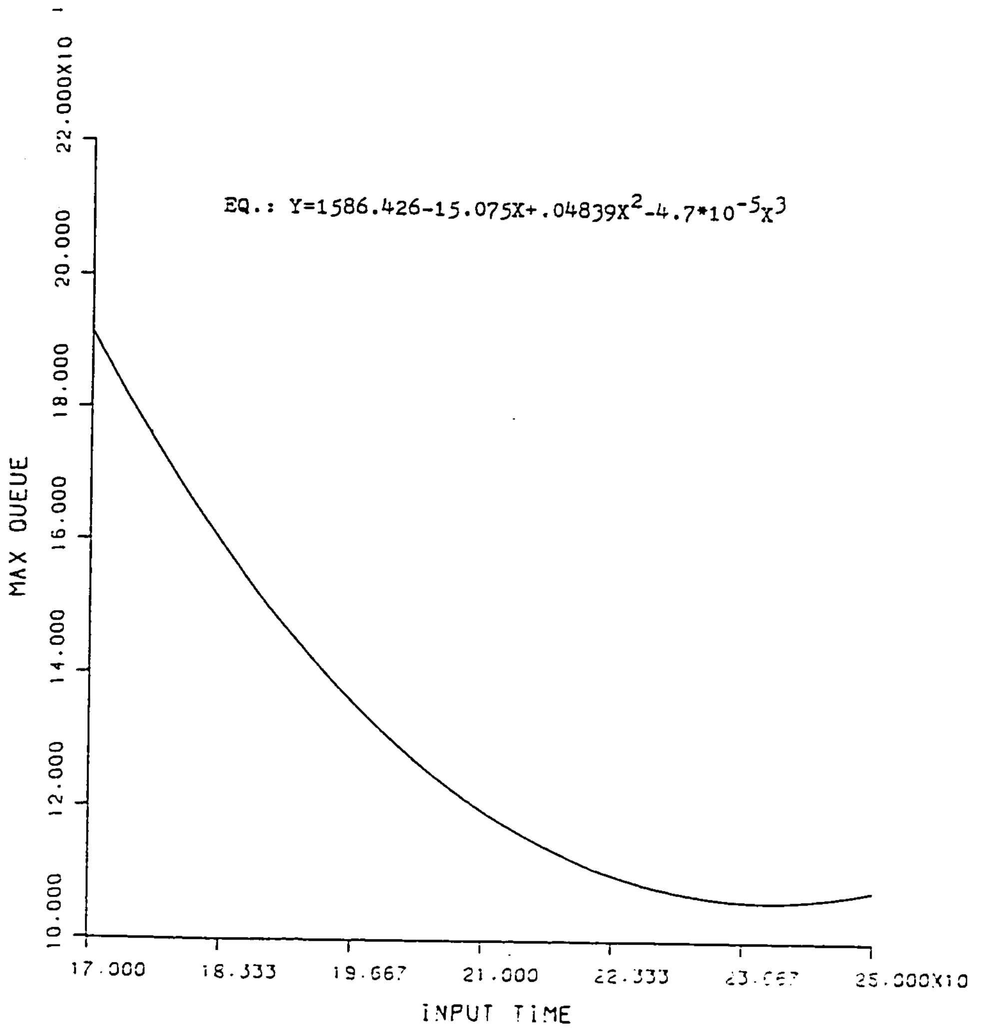


Fig. P

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

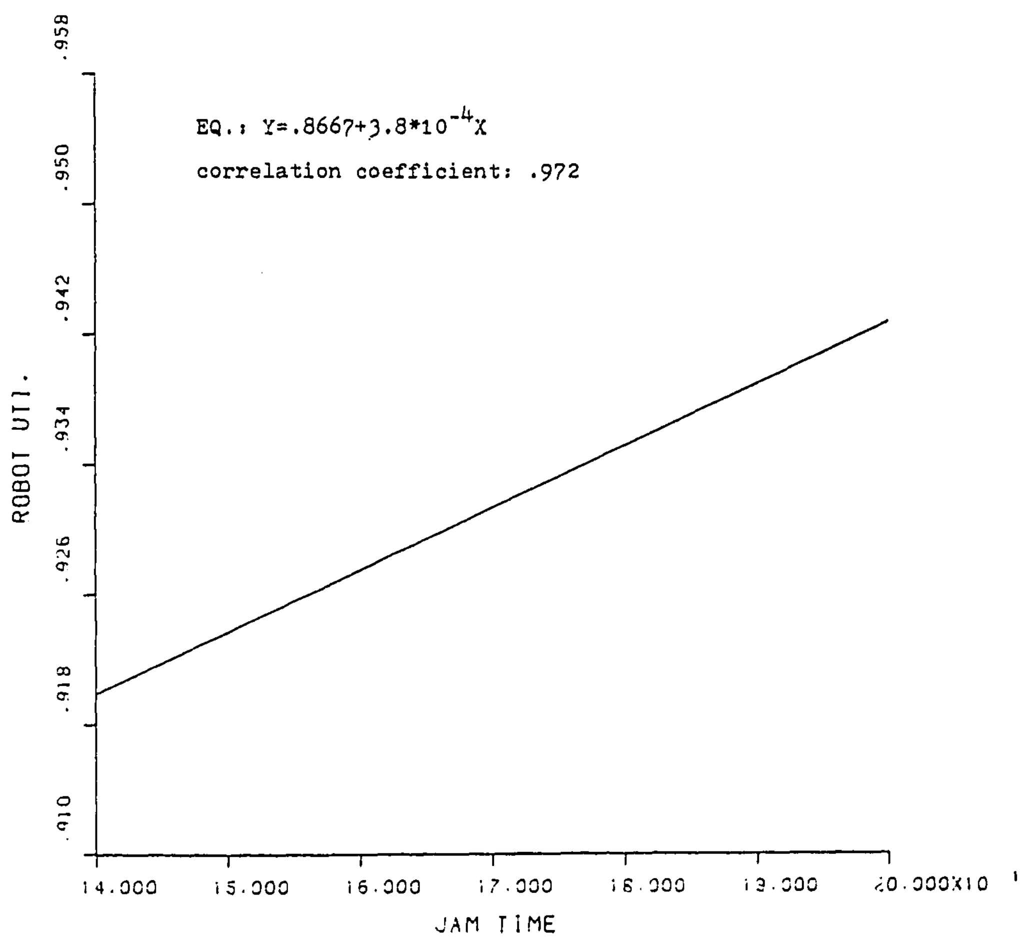


Fig. P

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

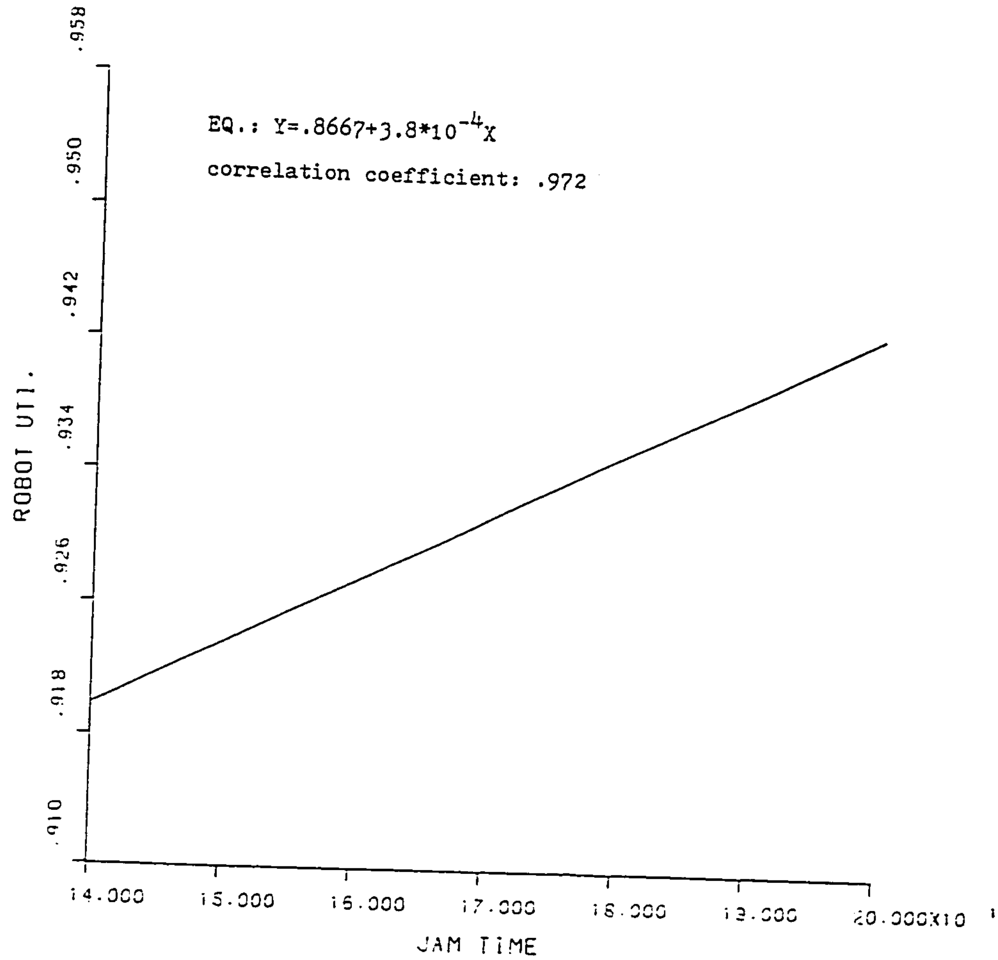


Fig. Q

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

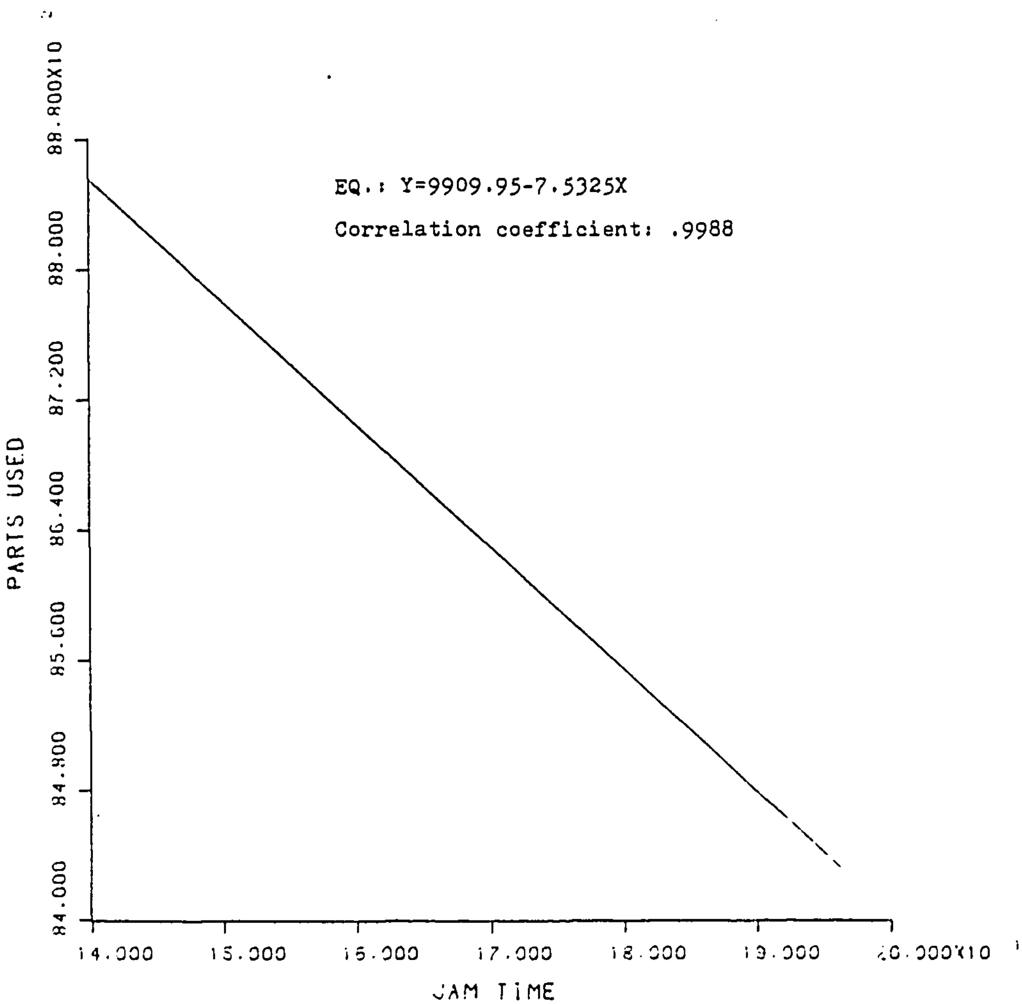


Fig. Q

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

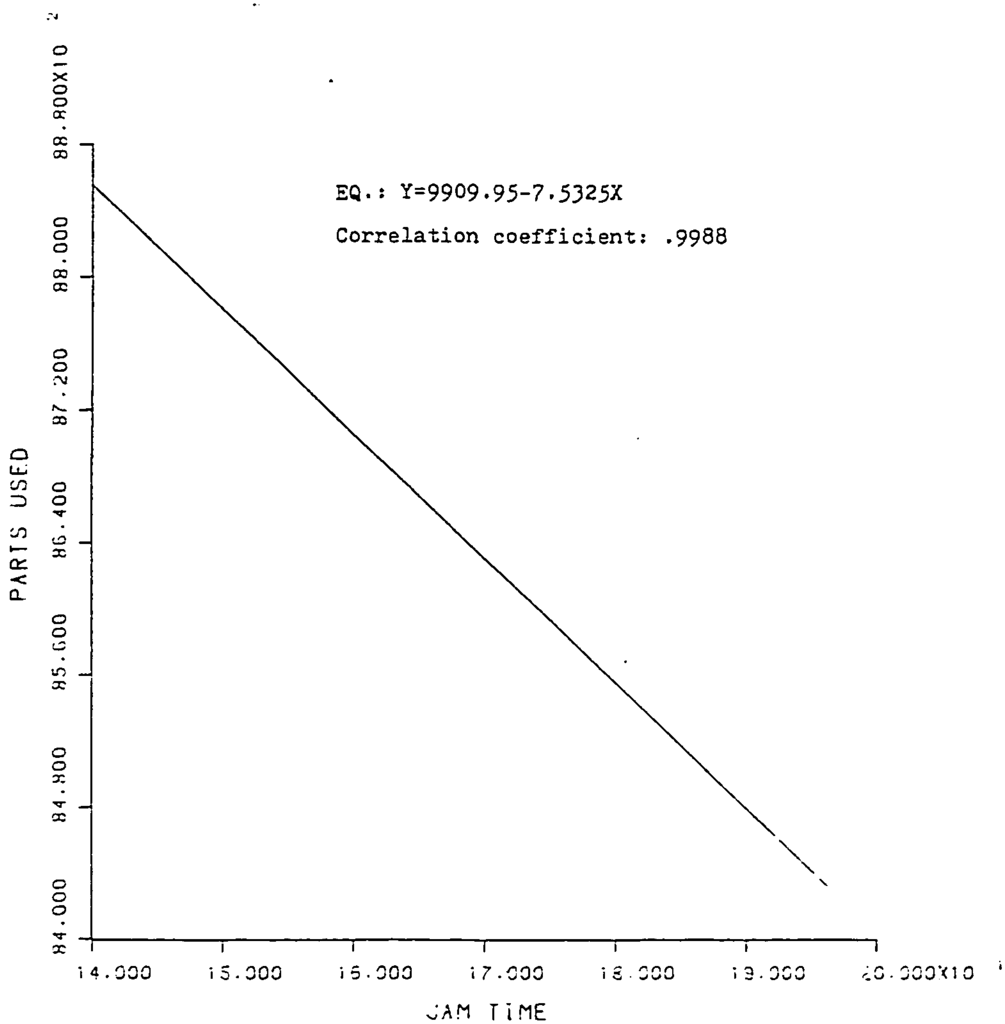


Fig. R

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

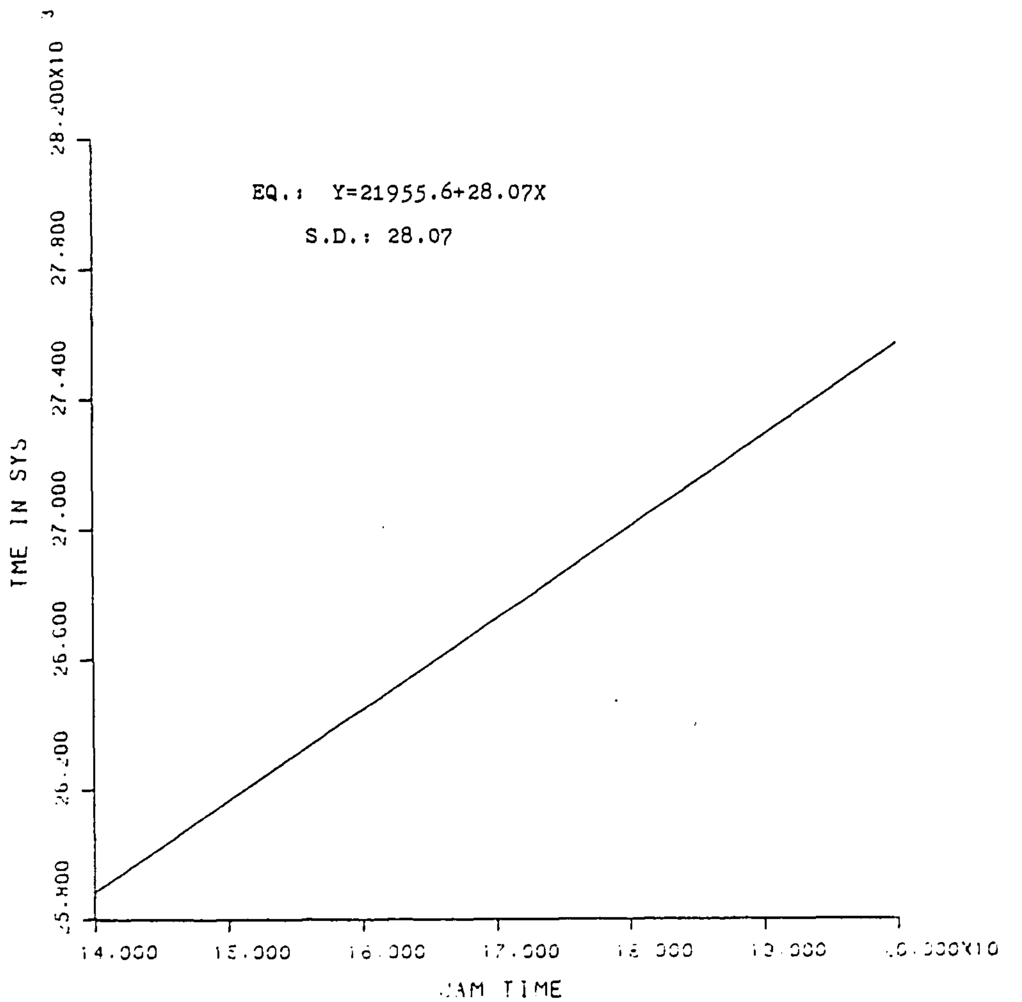


Fig. R

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

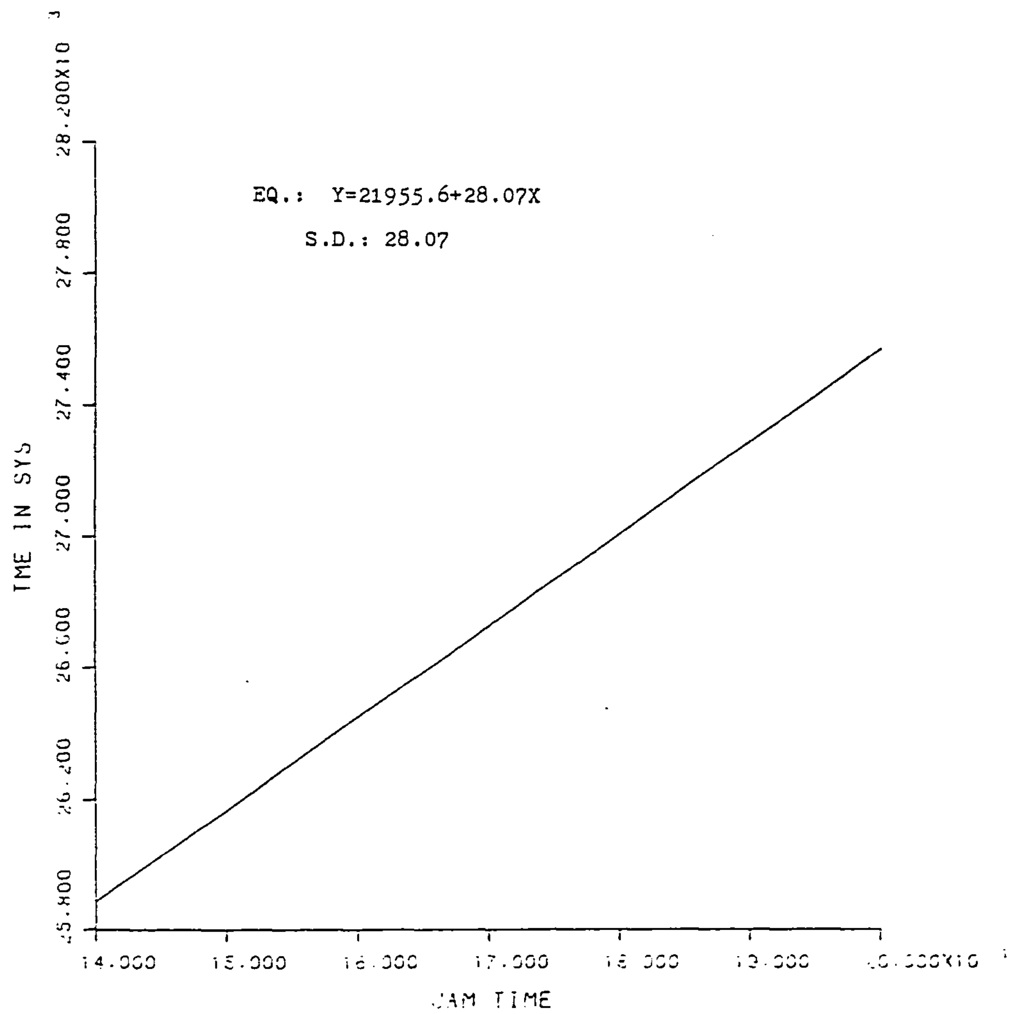


Fig. S

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

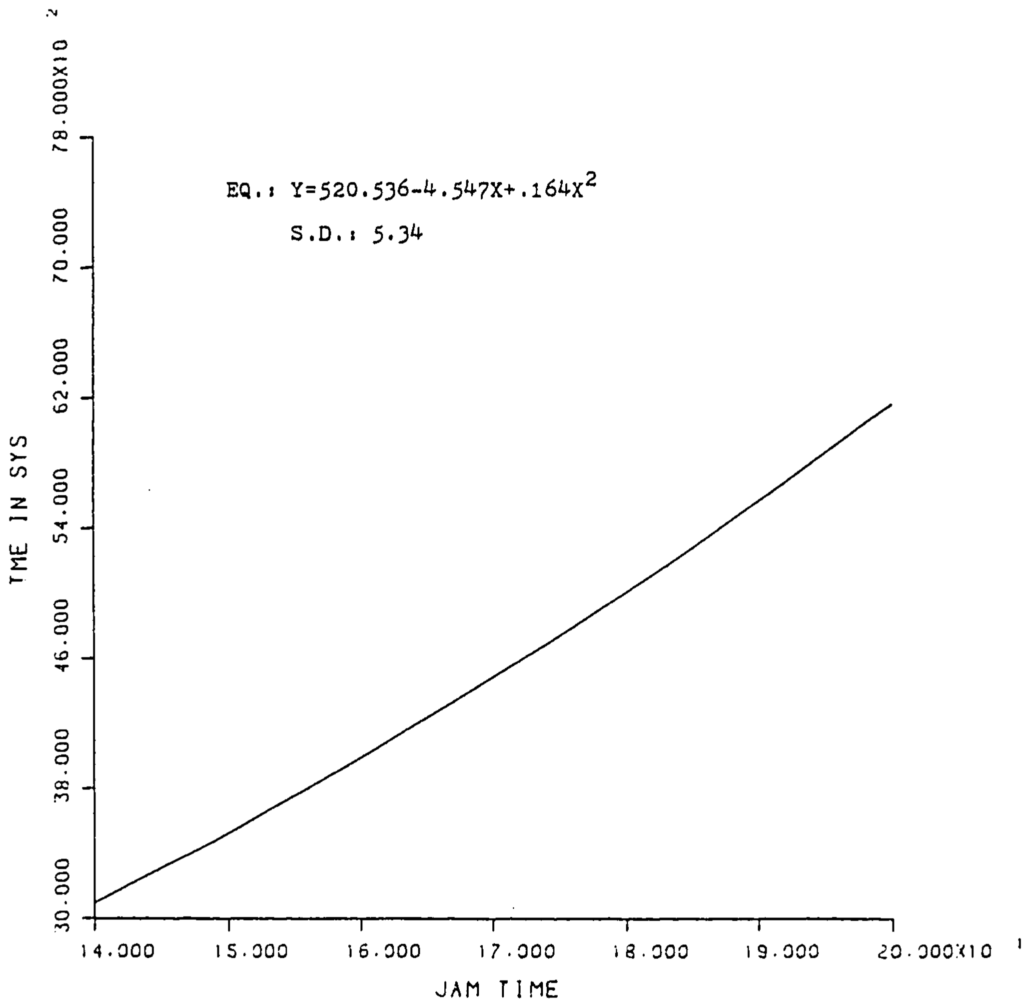


Fig. S

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

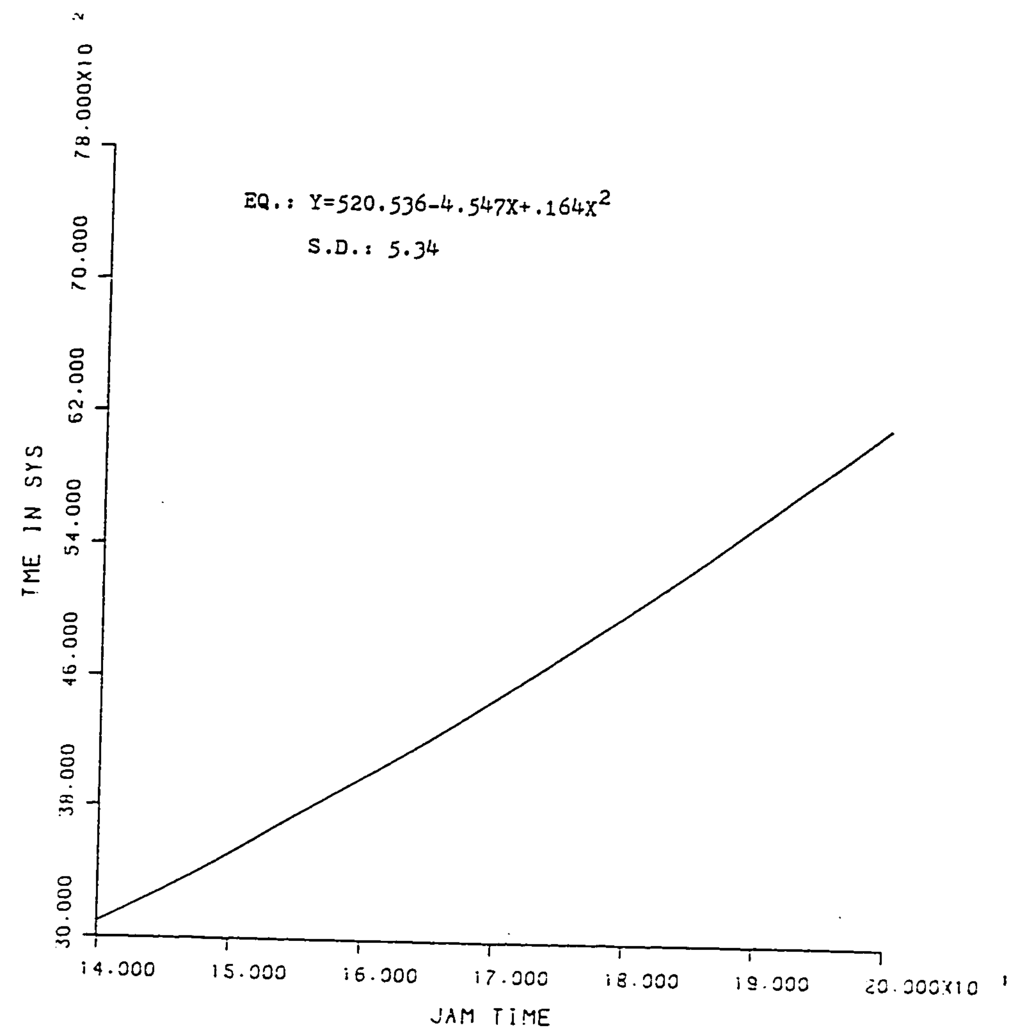


Fig. T

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

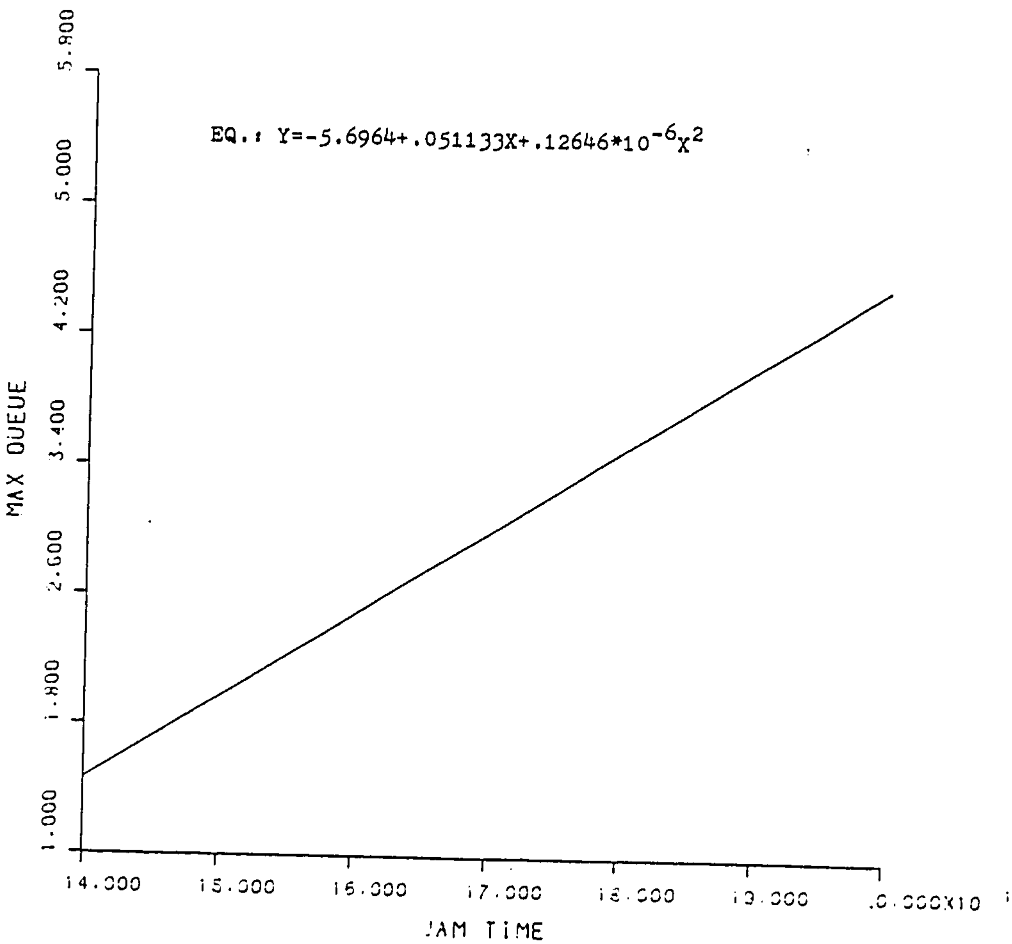


Fig. T

Assembly Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

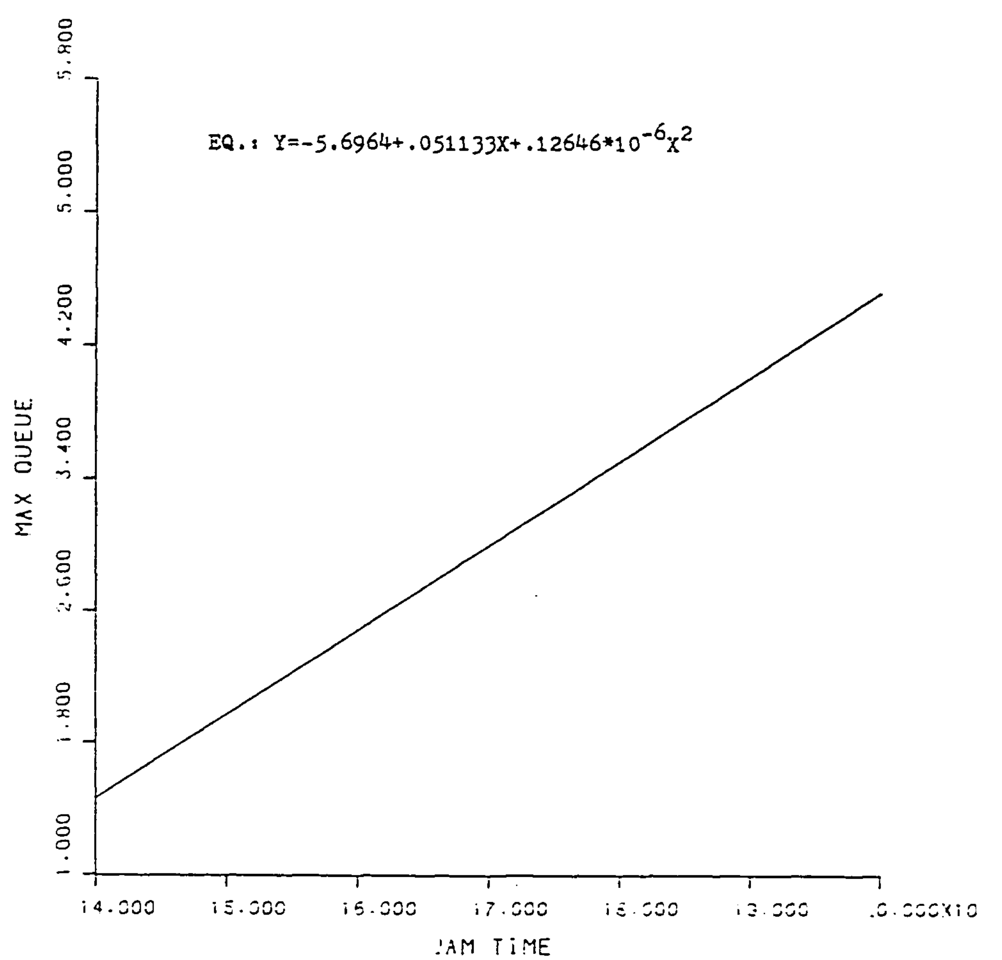


Fig. U

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

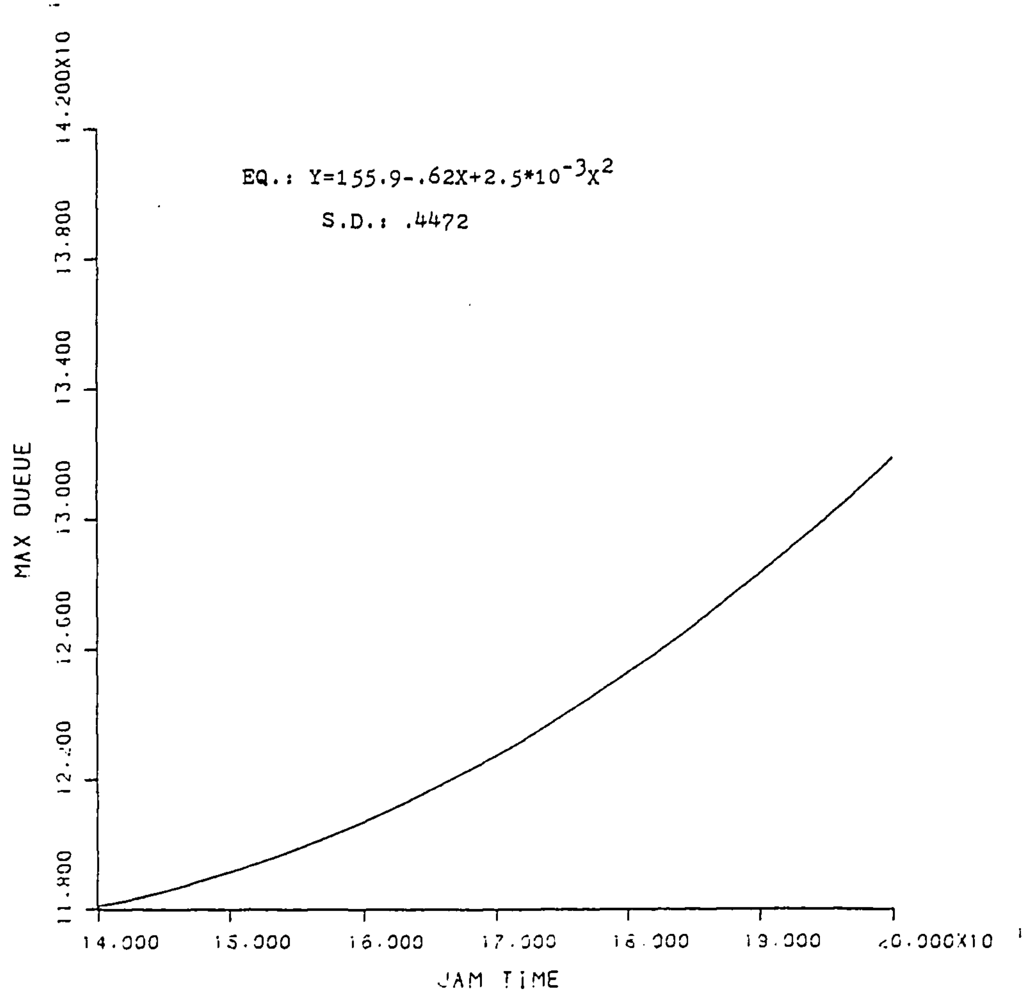


Fig. U

Palletizing Line

probability to have a jam occured : .01
time between successive pallets in : 200 seconds
no robot breakdown

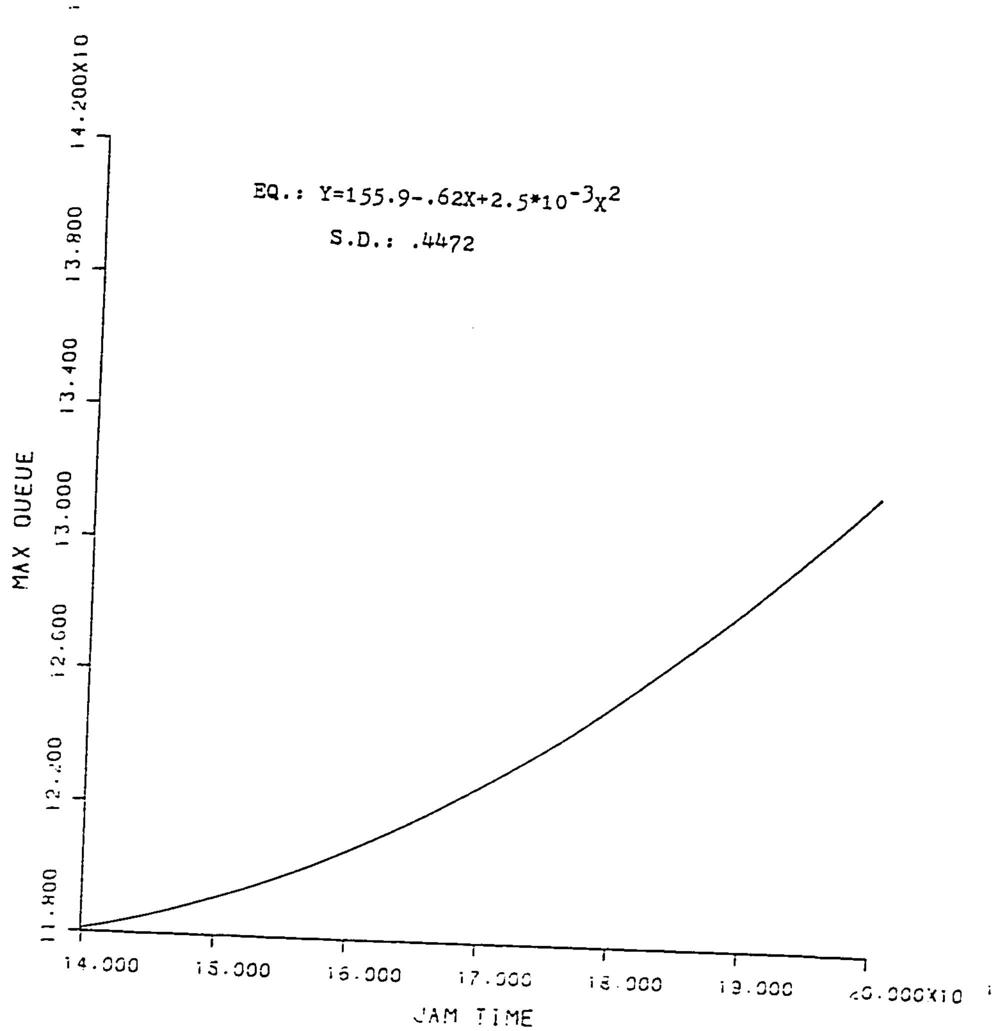


Fig. V

Palletizing Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

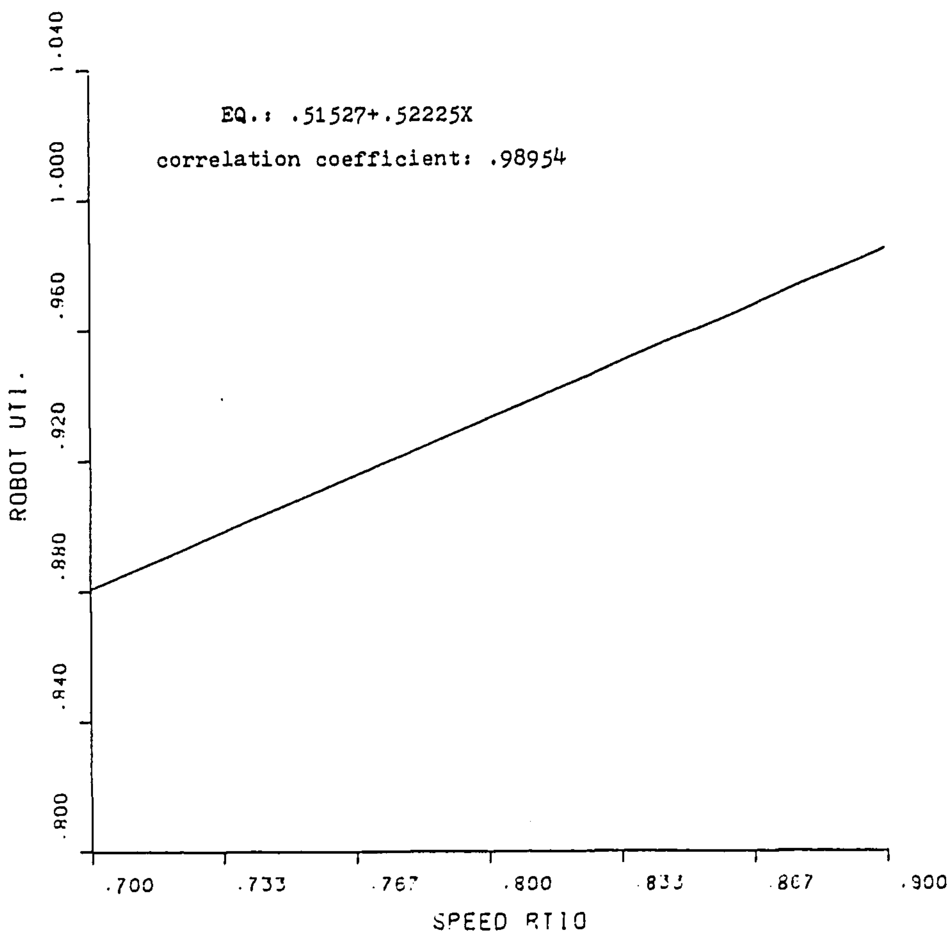


Fig. V

Palletizing Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

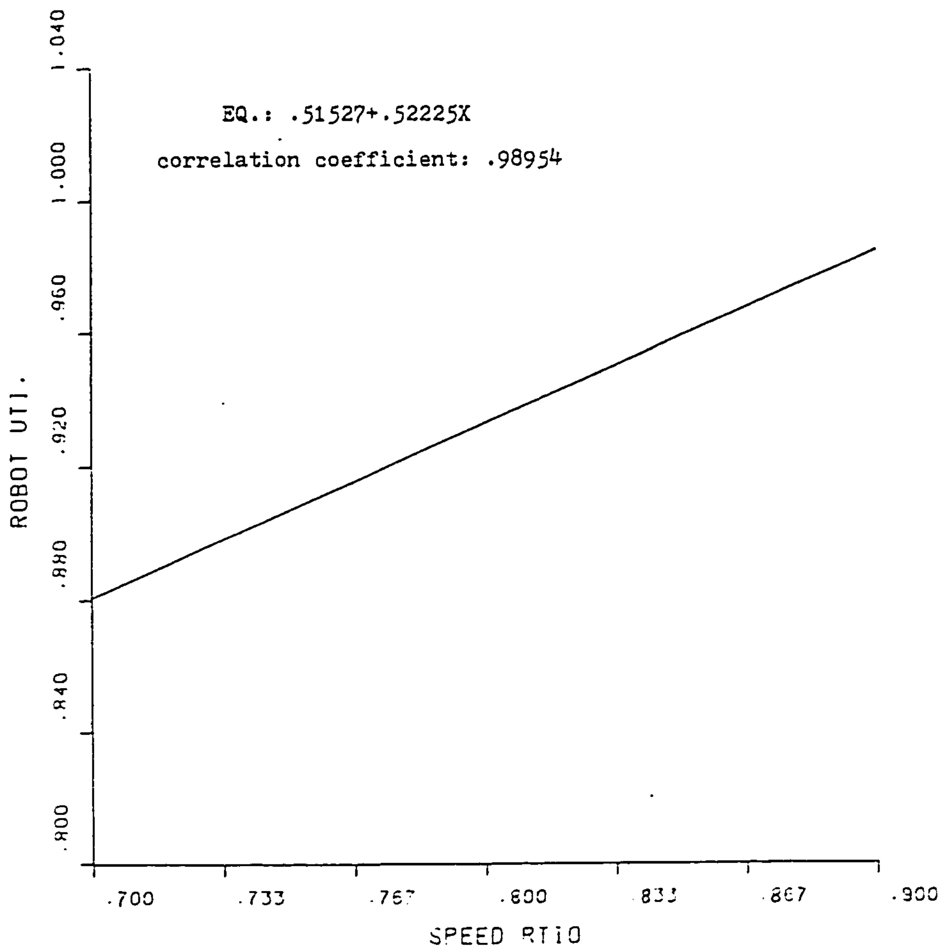


Fig. W

Assembly Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

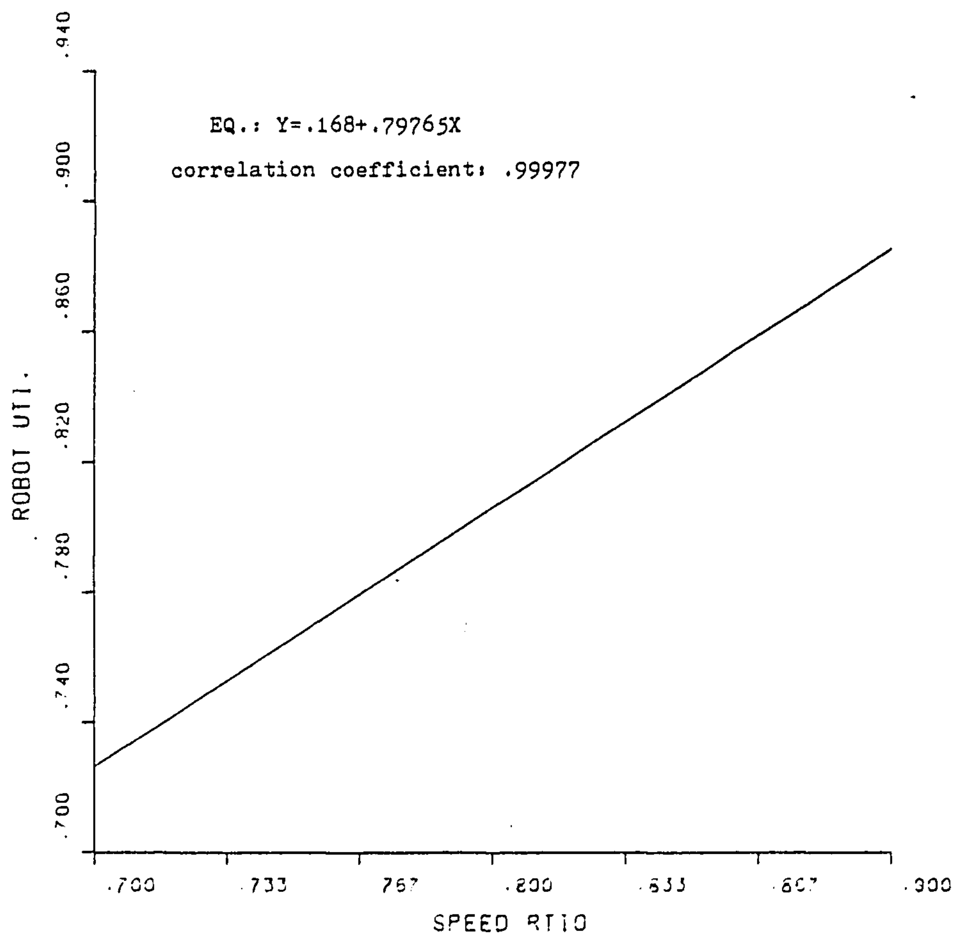


Fig. W

Assembly Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

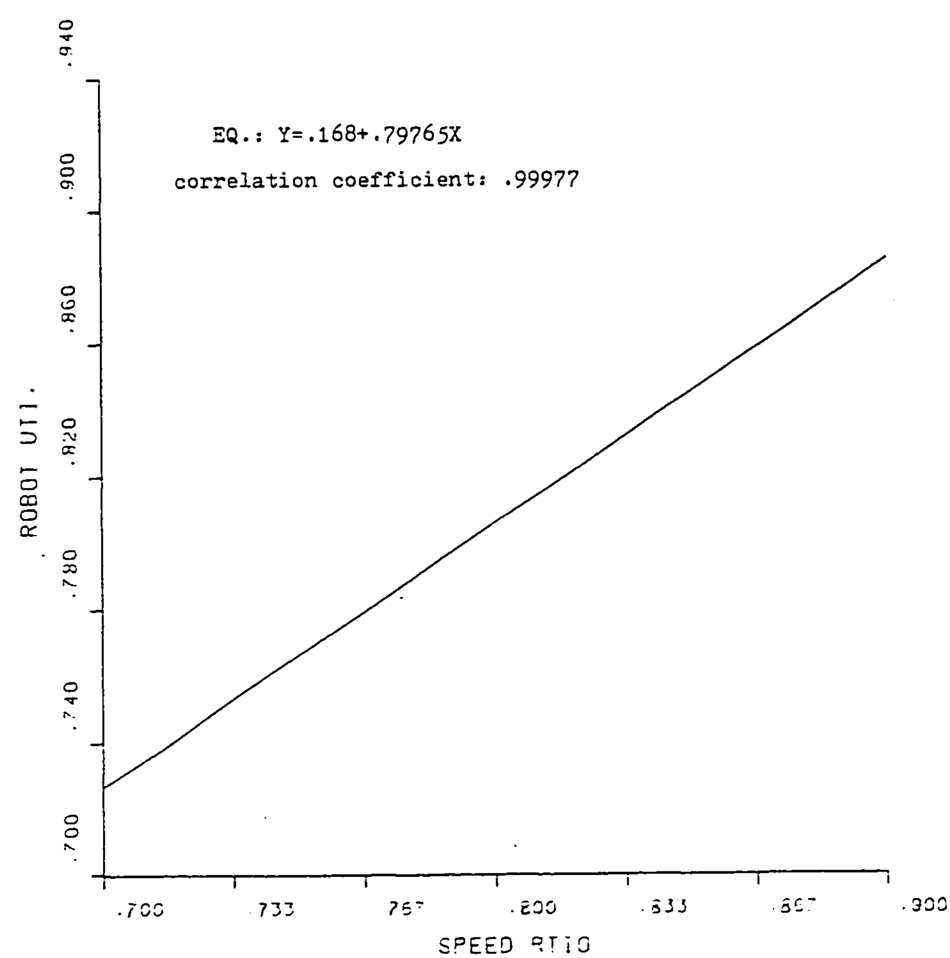


Fig. X

Assembly Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

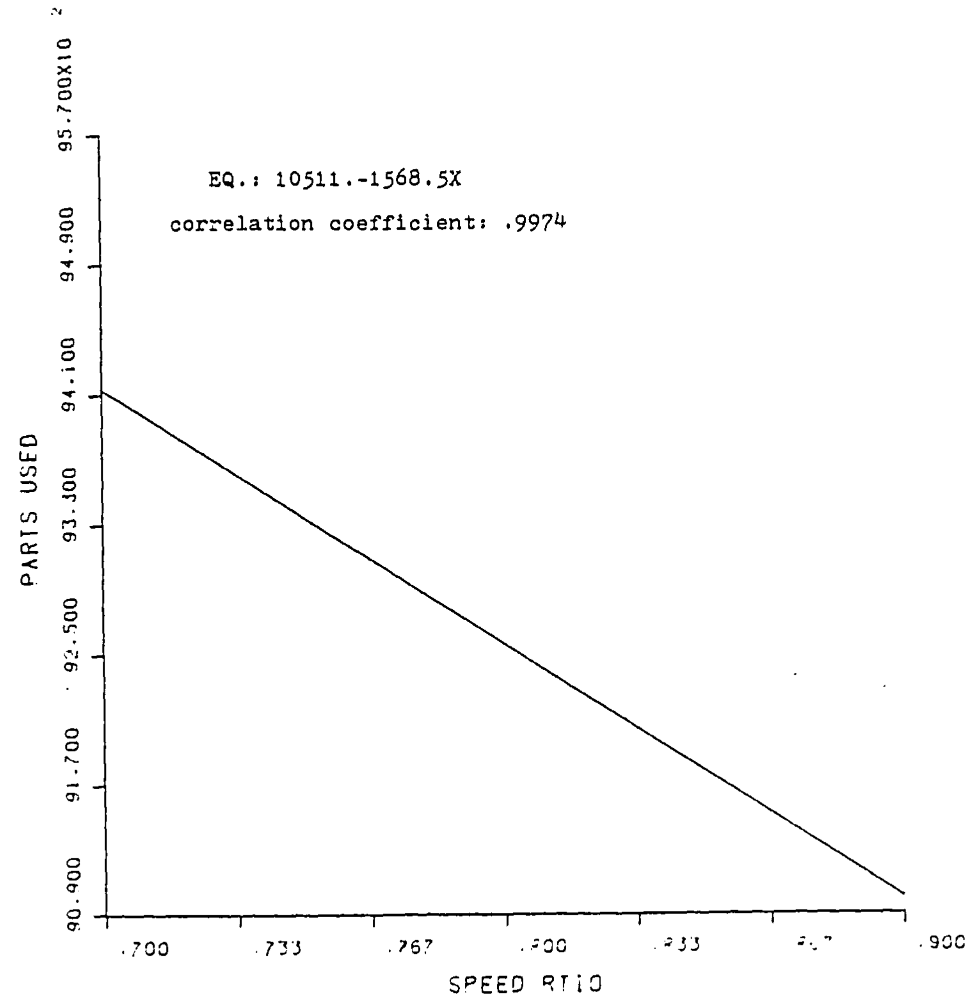


Fig. X

Assembly Line

time between successive pallets in : 200 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

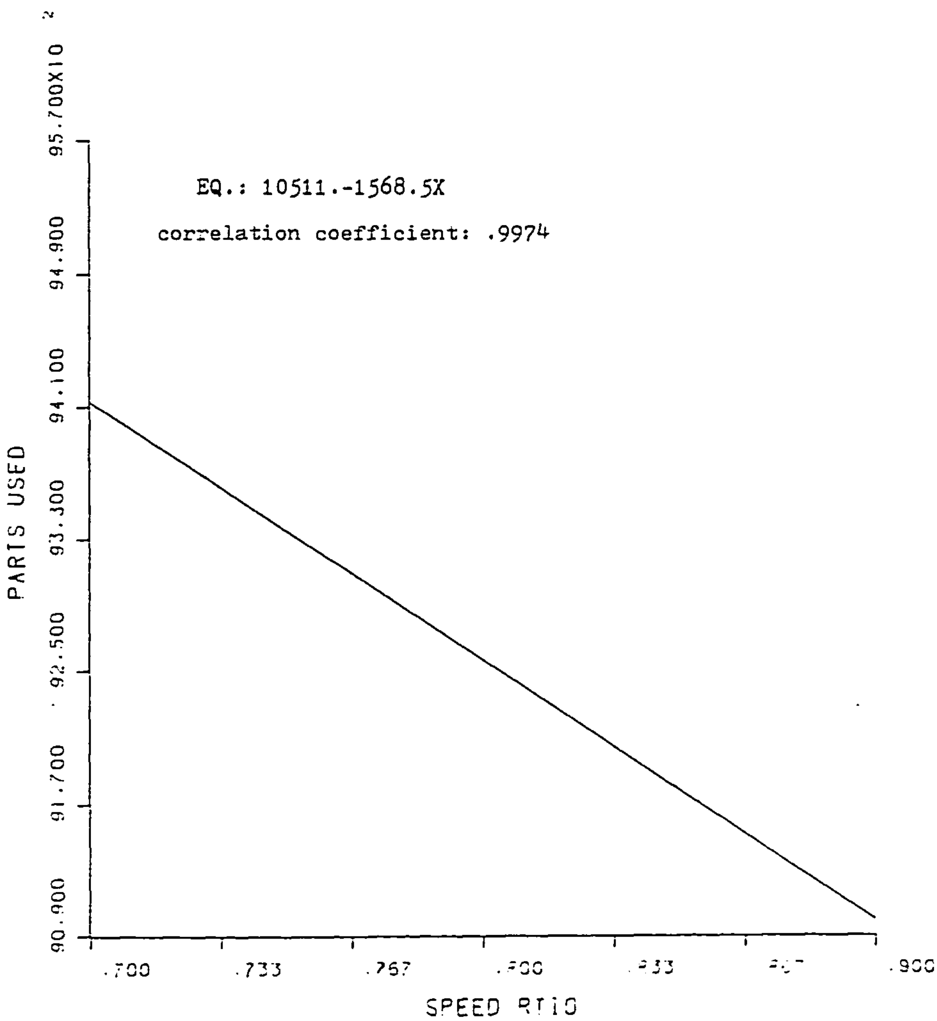


Fig. Y.

Palletizing Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

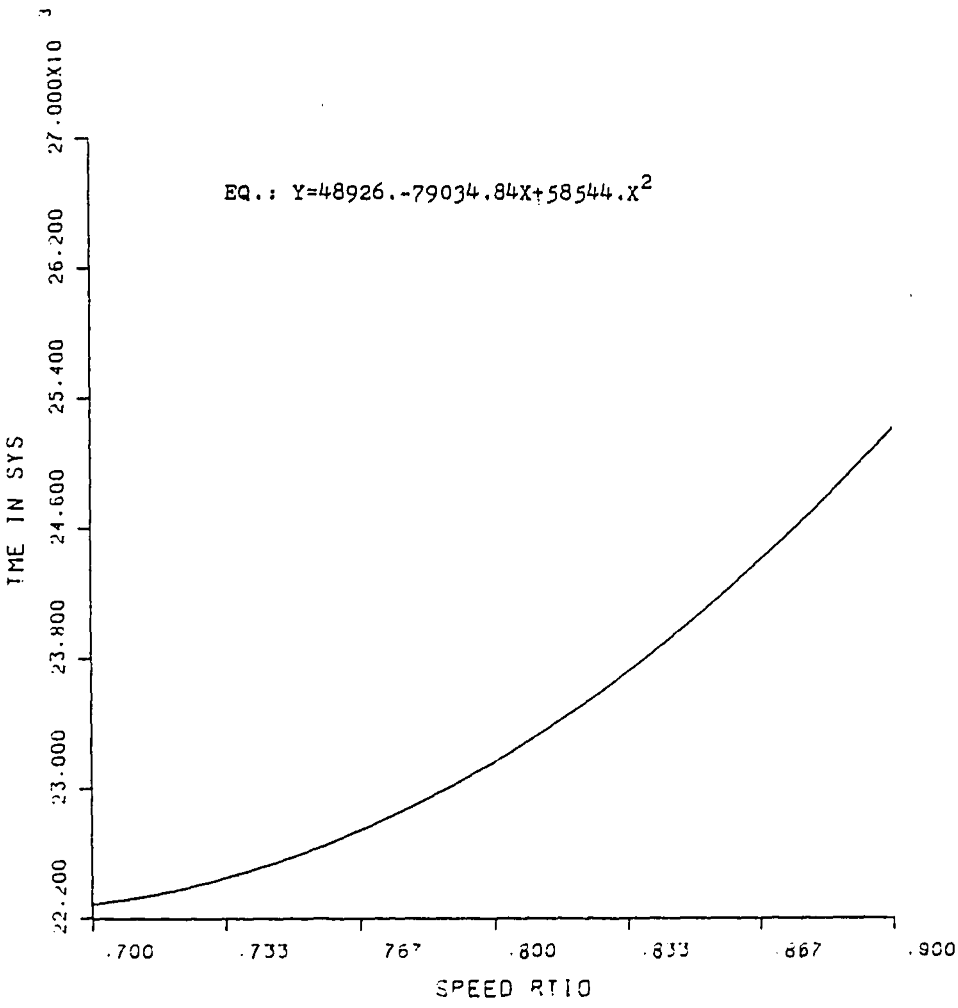


Fig. Y.

Palletizing Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

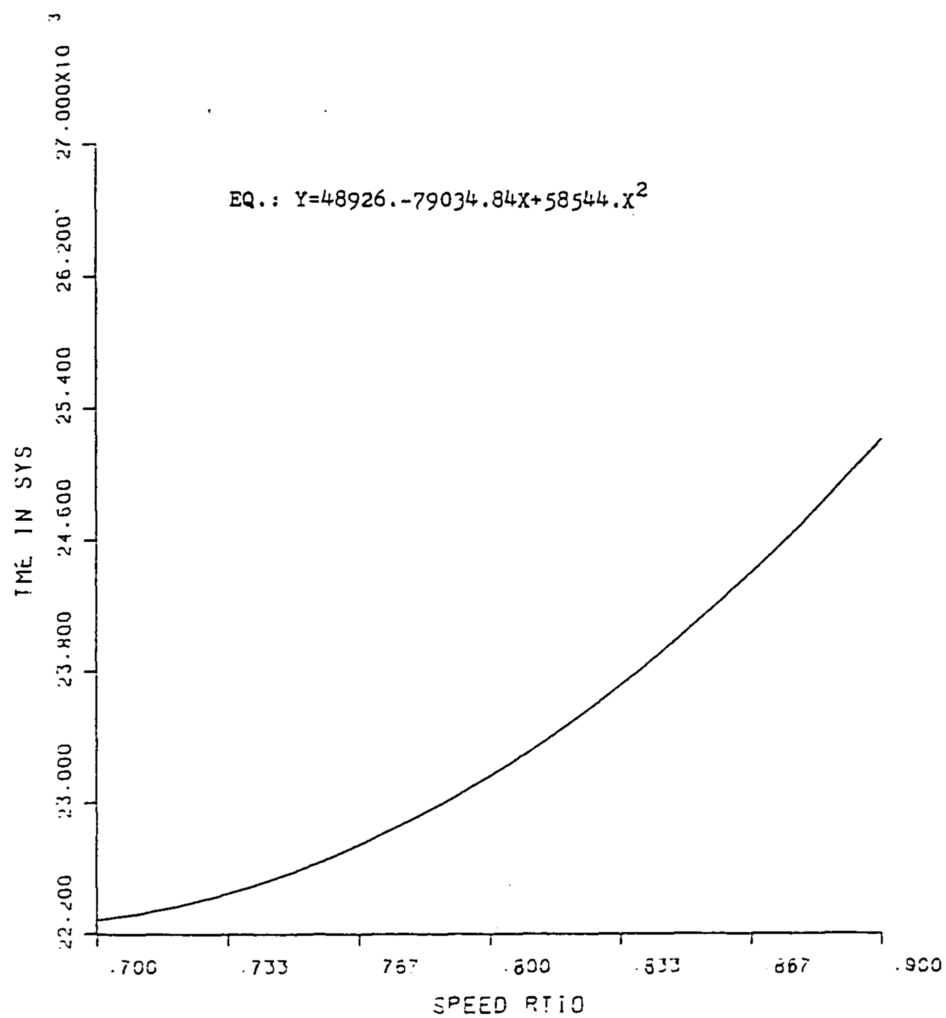


Fig. Z

Assembly Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

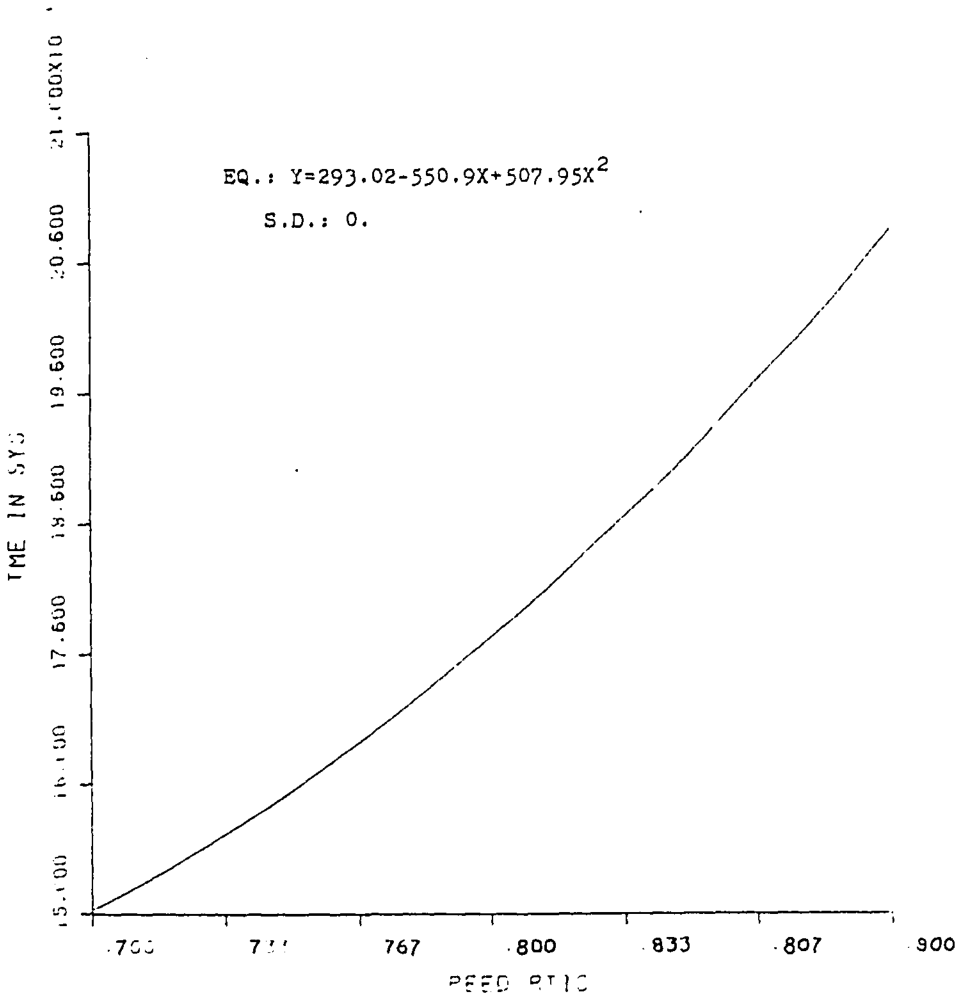


Fig. 2

Assembly Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

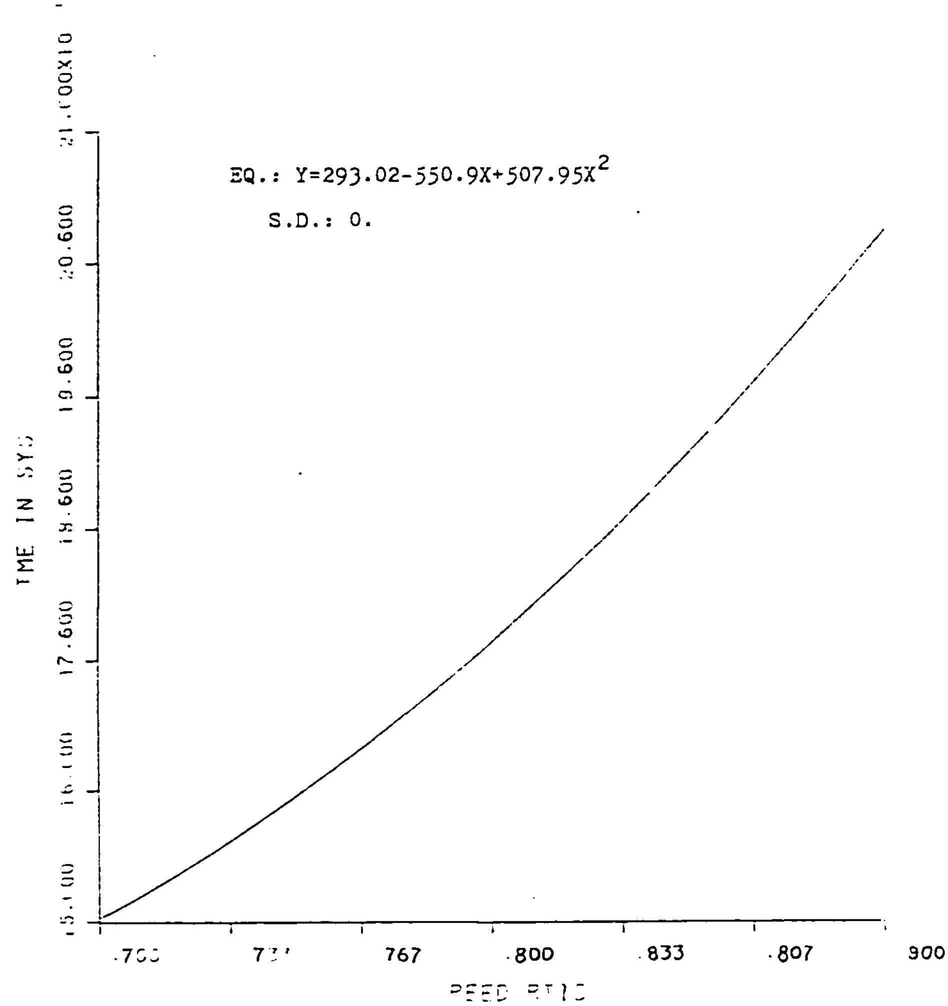


Fig. YY

Palletizing Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

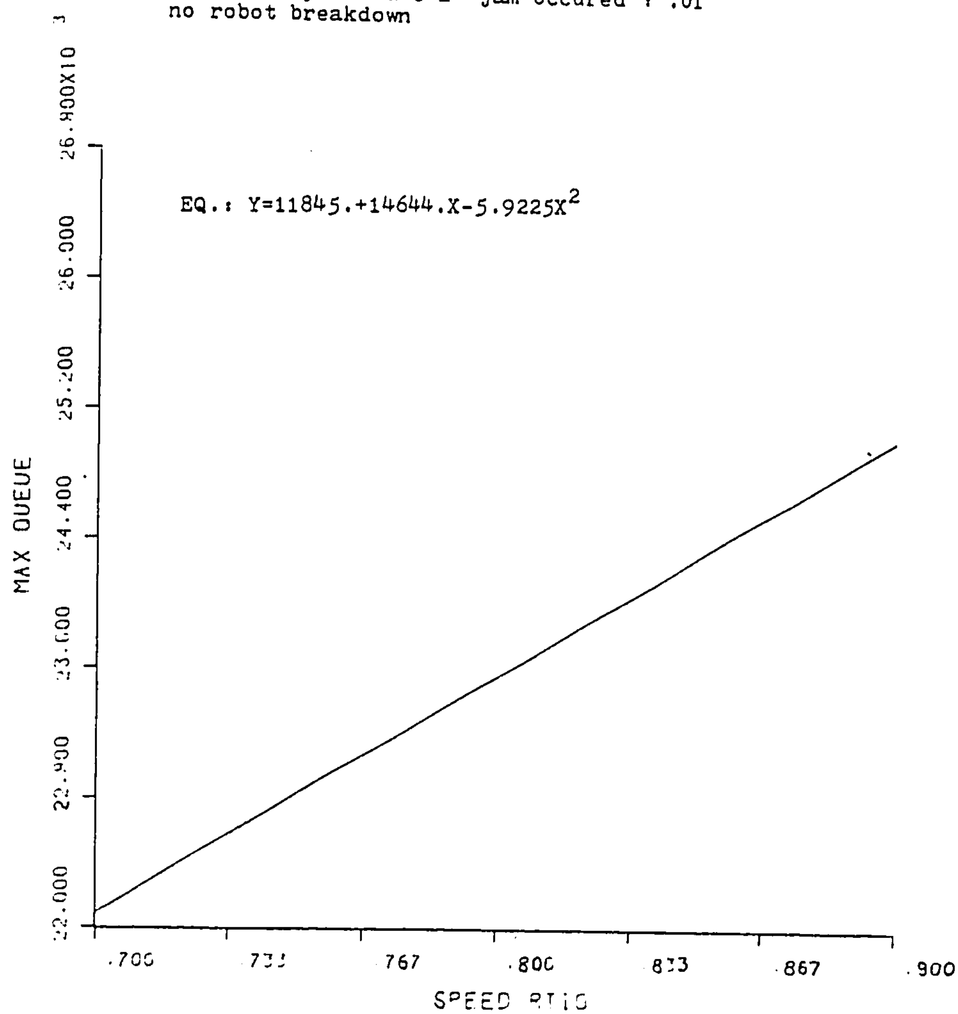


Fig. YY

Palletizing Line

time between successive pallets in : 200 seconds.
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

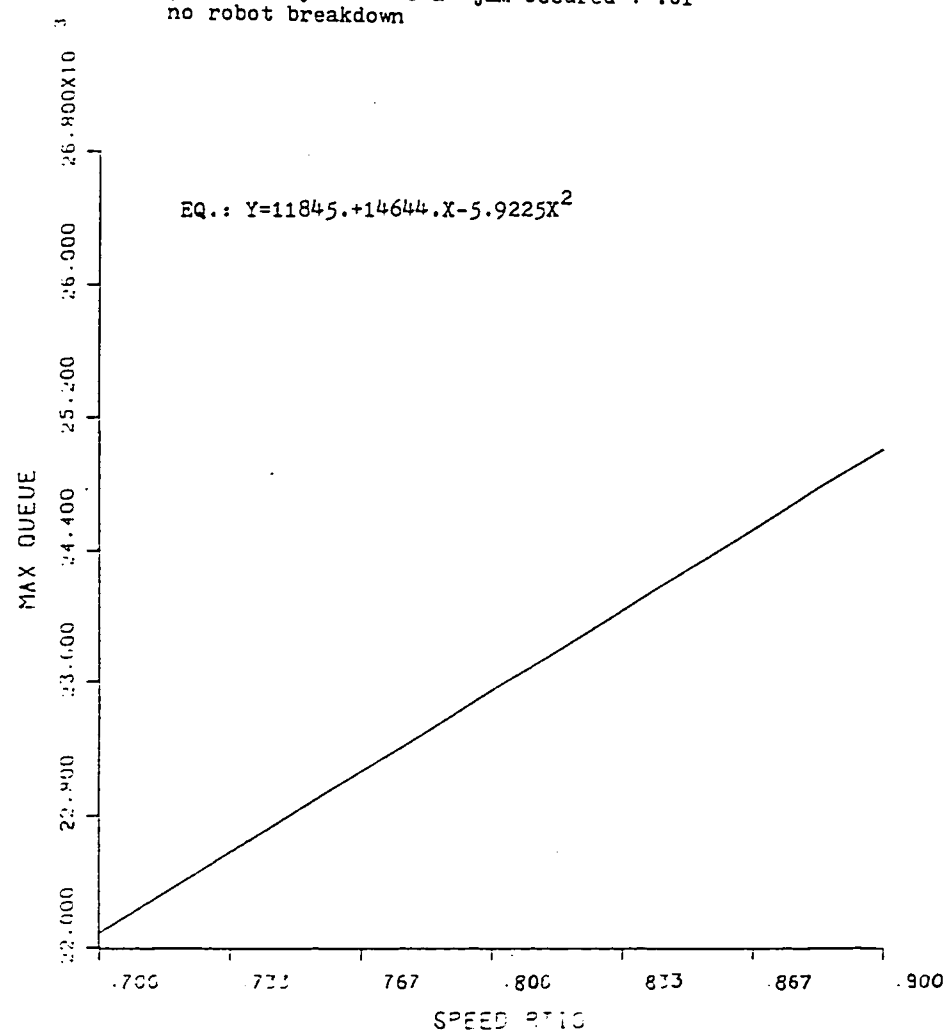


Fig. ZZ

Assembly Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown

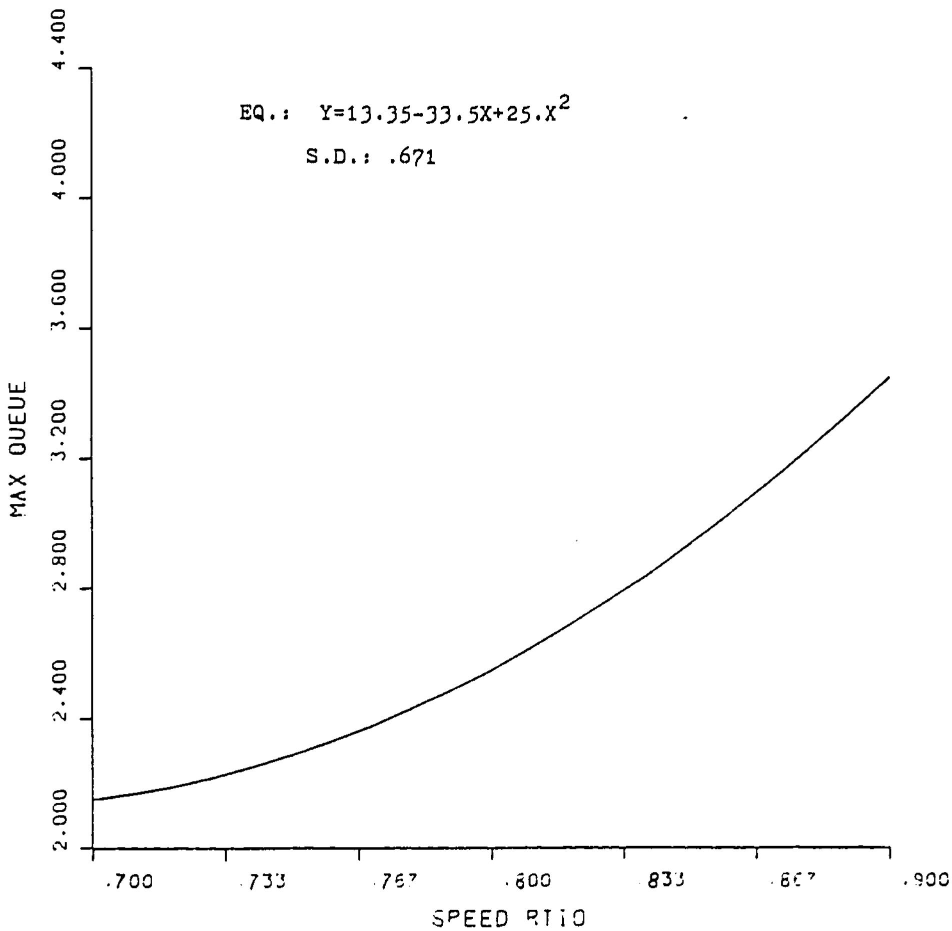
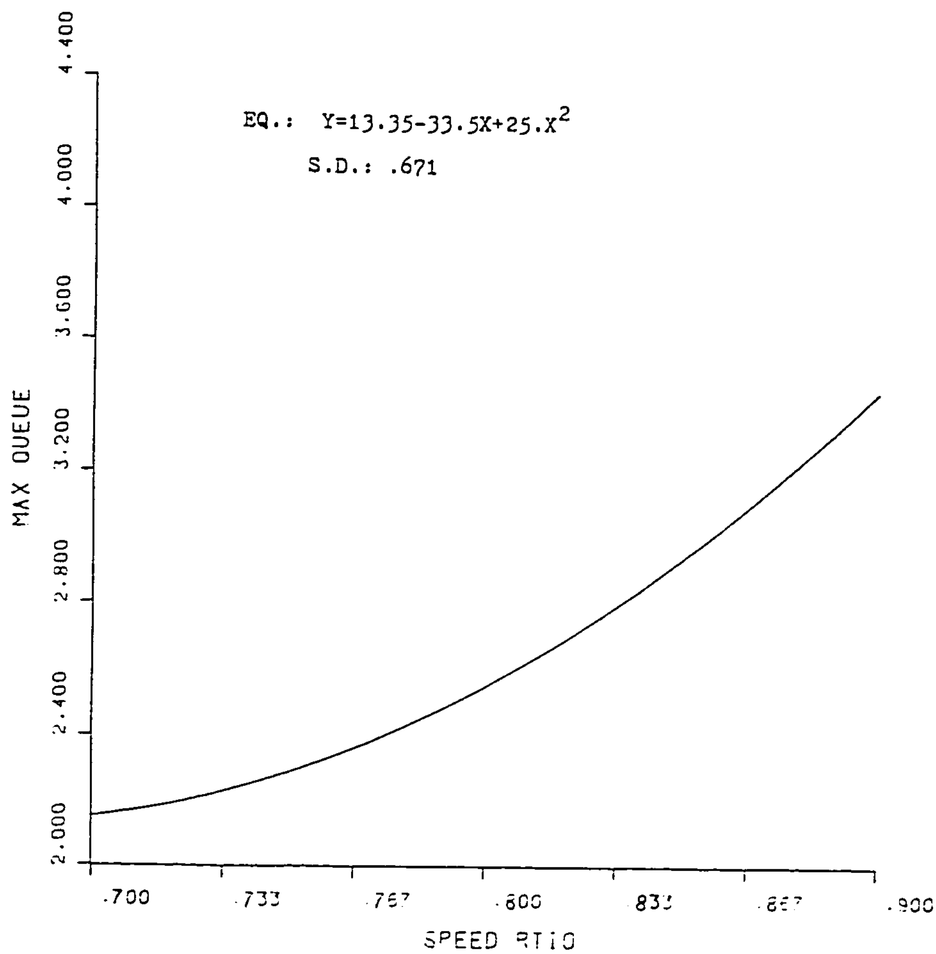


Fig. 22

Assembly Line

time between successive pallets in : 195 seconds
time needed for solving the jam : 200 seconds
probability to have a jam occured : .01
no robot breakdown



I.3 SIMULATION PROGRAM

```
        PROGRAM MAIN
        DIMENSION NSET(10000)
        COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
        9,MFA,MSTOP,NCLNR
        1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
        8,SSL(100),TNEXT,TNOW,XX(200)
        COMMON/UCOM1/ TPLCR(20),ASMBT(3),REPAR,FAST
        COMMON QSET(10000)
        EQUIVALENCE (NSET(1),QSET(1))
        OPEN(UNIT=5,DEVICE='DSK',FILE='SLIN.DAT',ACCESS='SEQIN')
        OPEN(UNIT=6,DEVICE='DSK',FILE='SLOUT.DAT',ACCESS='SEQOUT')
        OPEN(UNIT=7,DEVICE='DSK',FILE='TEMP.DAT',ACCESS='SEQINOUT')
        NNSET=10000
        NCRDR=5
        NPRNT=6
        NTAPE=7
        CALL SLAM
        STOP
        END
C
C
C
C
        SUBROUTINE INTLC
        COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
        9,MFA,MSTOP,NCLNR
        1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
        8,SSL(100),TNEXT,TNOW,XX(200)
        COMMON/UCOM1/ TPLCR(20),ASMBT(3),REPAR,FAST
        COMMON QSET(10000)
CCCCC   ROBOT PLACING TIME FOR EACH TYPE OF PRODUCT
        DATA TPLCR/8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5,
        1          8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5,8.5/
CCCCC
        DATA ASMBT/7.,0.,12./
CCCCC   TIME TO REPAIR THE JAM
        REPAR=200.
C
        XX(1)=1.
ccccc  NUMBERS IN A CASE
        XX(2)=100.
CCCCC    NUMBERS OF PARTS IN A PALLET
        XX(3)=20.
CCCCC
        XX(8)=7.
CCCCC   TIME FOR PALLET TO BE RELEASED
```

```
      XX(9)=1.
CCCCC
CCCCC
      XX(10)=10.
CCCCC TIME FOR PALLET TO RECYCLE IN SYSTEM 1
      XX(11)=7.
CCCCC
      XX(12)=1.
CCCCC NUMBER OF STAGES IN ASSEMBLY
      XX(13)=3.
CCCCC SUCCESSFUL RATE FOR PLACING THE PARTS ON PALLET
      XX(14)=.99
CCCCC INDIVIDUAL SUCCESSFUL RATE FORR THE PARTS ON PALLET
      XX(16)=.99**7
      XX(17)=.99*12
CCCCC INCOMING RATE OF PALLET
CCCCC
      XX(15)=30.
CCCCC RATIO OF THE ROBOT PROCESS TIME
      FAST=1.
      RETURN
      END
C
C
      SUBROUTINE EVENT(I)
      GO TO (1,2)I
1     CALL ARVL
      RETURN
2     CALL RWORK
      RETURN
      END
C
C
      SUBROUTINE ARVL
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
     9,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     8,SSL(100),TNEXT,TNOW,XX(200)
      COMMON/UCOM1/ TPLCR(20),ASMBT(3),REPAR,FAST
      COMMON QSET(10000)
      IF(ATRIB(2).EQ.XX(13))GO TO 50
      IF(ATRIB(2).GT.XX(13))CALL ERROR(1001)
      IF(ATRIB(3).EQ.0.)GO TO 20
      ATRIB(2)=ATRIB(2)+1.
      CALL ENTER(1,ATRIB)
      RETURN
20    CONTINUE
      TT=USERF(2)
```

```
      IF(TT.LE.0.)CALL ERROR(1001)
      ATRIB(2)=ATRIB(2)+1.
      CALL SCHDL(2,TT,ATRIB)
      RETURN
50    CONTINUE
      CALL ENTER(2,ATRIB)
      RETURN
      END
C
C
      SUBROUTINE RWORK
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
     9,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     8,SSL(100),TNEXT,TNOW,XX(200)
      COMMON/UCOM1/ TPLCR(20),ASMBT(3),REPAR,FAST
      COMMON QSET(10000)
      CALL ENTER(1,ATRIB)
      RETURN
      END
C
C
C
      SUBROUTINE OTPUT

      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
     9,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     8,SSL(100),TNEXT,TNOW,XX(200)
      COMMON QSET(10000)
      WRITE(6,10)REPAR
      WRITE(6,20)XX(2)
      WRITE(6,30)XX(3)
      WRITE(6,80)XX(8)
      WRITE(6,90)XX(9)
      WRITE(6,140)XX(14)
      WRITE(6,150)XX(15)
10    FORMAT(10X,'TIME FOR SOLVING THE JAM=',F10.5)
20    FORMAT(10X,'BATCH SIZE              =',F10.5)
30    FORMAT(10X,'No. OF PARTS IN A PALLET=',F10.5)
80    FORMAT(10X,'TRANSFER TIME FROM 1-2  =',F10.5)
90    FORMAT(10X,'TIME FOR PALLET RELEASED=',F10.5)
140   FORMAT(10X,'PROBABILITY OF PASS     =',F10.5)
150   FORMAT(10X,'TIME BET. PALLET ARRIVAL=',F10.5)
      RETURN
      END
C
C
```

```
      FUNCTION USERF(I)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II
     9,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     8,SSL(100),TNEXT,TNOW,XX(200)
      COMMON/UCOM1/ TPLCR(20),ASMBT(3),REPAR,FAST
      COMMON QSET(10000)
      GO TO (1,2,3,4,5,6,7,8)I
1     CONTINUE
      AA=REPAR*.9
      BB=REPAR*1.1
      GG=0.
      IF(DRAND(1).GT.XX(14))GG=UNFRM(AA,BB,1)
      USERF=GTABL(TPLCR,XX(6),1.,XX(3),1.)
      USERF=USERF*FAST
      IF(GG.GT.0.)USERF=USERF/2.
      USERF=USERF+GG
      RETURN
2     CONTINUE
CCCCC TIME FOR PALLET TO RECYCLE AND PROCESS IN SYSTEM 2
      USERF=11.
      RETURN
3     CONTINUE
      USERF=UNFRM(20.,40.,1)
      RETURN
4     CONTINUE
      USERF=EXPON(100000.,1)
      RETURN
5     CONTINUE
      RETURN
6     CONTINUE
      AA=REPAR*.9
      BB=REPAR*1.1
      GG=0.
      TX=XX(16)
      IF(ATRIB(2).GE.3.)TX=XX(17)
      IF(ATRIB(2).EQ.2.)TX=1.
      IF(DRAND(1).GT.TX)GG=UNFRM(AA,BB,1)
      USERF=GTABL(ASMBT,ATRIB(2),1.,XX(13),1.)
      USERF=USERF*FAST
      IF(GG.GT.0.)USERF=USERF/2.
      USERF=USERF+GG
      USERF=USERF+GG
      RETURN
7     CONTINUE
      USERF=EXPON(100000.,1)
      RETURN
8     CONTINUE
```

```
        USERF=EXPON(30.,1)
        RETURN
        END
```

NETWORK PROGRAM

```
GEN,SUN,INPUT1,3/7/1983,10,,NO,,NO;
LIM,9,4,1000;
SEEDS,756375957(1);
INTLC,XX(6)=1.;
NETWORK;
      RESOURCE/PLCER(1),4,2;
      RESOURCE/ASMBY(1),8,6;
      RESOURCE/PLLET(30),7;
      RESOURCE/PARTS(100),5;
      GATE/IN,OPEN,1;
      GATE/OUT,CLOSE,3;
;
;
      CREATE,XX(15),,1;
AGAIN GOON;
      QUEUE(9),100;
      ACT,0.001;
      ASSIGN,ATRIB(3)=NNQ(1)+NNACT(4);
      GOON,1;
      ACT/3,2000,ATRIB(3).GE.XX(2),AGAIN;
      ACT(1)/4,1;
      ASSIGN,ATRIB(1)=TNOW;
      AWAIT(1),IN;
      ACT,,,COUNT;
      ACT/2;
SUN   AWAIT(2),PLCER;
PART  AWAIT(5),PARTS;
      ASSIGN,XX(5)=XX(5)+1;
      ACT/1,USERF(1);
      GOON;
      ACT,,,GO;
      ACT,1,XX(5).EQ.XX(2),ONE;
GO    GOON,1;
      ACT,,NNGAT(OUT).EQ.0,END;
      ACT,,,NEXT;
NEXT  FREE,PLCER;
      ACT,XX(11);
LOOP  GOON,1;
      ACT,5.,NNGAT(IN).EQ.0,LOOP;
      ACT,,,SUN;
;
```

```
;
END    AWAIT(3),OUT;
       FREE,PLCER;
       COLCT,INT(1),TIME IN PLCER;
       ASSIGN,XX(7)=XX(7)+1;
       ACT,,XX(7).EQ.XX(2);
       CLOSE,OUT;
       OPEN,IN;
       ASSIGN,XX(7)=0;
       TERM;
;
;
ONE    ASSIGN,XX(6)=XX(6)+1,
              XX(5)=0;
       ACT,,XX(6).EQ.XX(3);
       OPEN,OUT;
       ASSIGN,XX(6)=1;
       TERM;
;
COUNT  ASSIGN,XX(4)=XX(4)+1;
       ACT,,XX(4).EQ.XX(2);
       CLOSE,IN;
       ASSIGN,XX(4)=0;
       TERM;
;
;
BREAK  CREATE,,;
       ACT,USERF(4);
       PREEMPT(4),PLCER;
       ACT,USERF(3);
       FREE,PLCER;
       ACT,,,BREAK;
;
CASE   CREATE,400.,,1;
       ACT,XX(12);
       ALTER,PARTS/XX(2);
       TERM;
;
;
;
;
CHEN   CREATE,XX(15),,1;
       ASSIGN,ATRIB(4)=TNOW;
       AWAIT(6),ASMBY;
       AWAIT(7),PLLET;
       ASSIGN,ATRIB(2)=1;
JASSI  ASSIGN,ATRIB(3)=USERF(6);
       ACT,ATRIB(3);
```

```
       EVENT,1;
       TERM;
;
;
       ENTER,1;
       ACT,,,JASSI;
;
;
       ENTER,2;
       FREE,ASMBY;
       ACT,,,DATA;
DATA   COLCT,INT(4),TIME IN ASMBY;
       ACT,,,CYCLE;
CYCLE  GOON;
       ACT,XX(9);
       FREE,PLLET/+1;
       TERM;
;
;
CHANG  CREATE,,;
       ACT,USERF(7);
       PREEMPT(8),ASMBY;
       ACT,USERF(8);
       FREE,ASMBY;
       ACT,,,CHANG;
       END;
INIT,0.,29800.;
TIMST,XX(5),NO. IN CASE;
TIMST,XX(6),NO. IN PALLET;
TIMST,XX(15),RATE OF INCOMING;
MONTR,CLEAR,1000.;
FIN;
```

VITA

The author was born in Taipei, Taiwan, The Republic of China, on April 9, 1957, the son of Tung-Yun Sun and Melin Sun. He completed high school in 1975, and attended National Tsing Hua University, Hsinchu, Taiwan from 1975 to 1979. He received his Bachelor of Science degree in 1979, with a major in Industrial Engineering. Upon graduation, he served in the Chinese Army as a Welfare Officer for two years. After that, he decided to continue his education with graduate study in the United States, and enrolled at Lehigh University in the Department of Industrial Engineering.